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Examination session (May or November)	MAY	Year	2015

Diploma Programme subject in which this extended essay is registered: ESS

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Title of the extended essay: WHAT TYPE OF HOUSING SHOULD ROME BUILD.

Candidate's declaration

This declaration must be signed by the candidate; otherwise a mark of zero will be issued.

The extended essay I am submitting is my own work (apart from guidance allowed by the International Baccalaureate).

I have acknowledged each use of the words, graphics or ideas of another person, whether written, oral or visual.

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This is the final version of my extended essay.

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Please comment, as appropriate, on the candidate's performance, the context in which the candidate undertook the research for the extended essay, any difficulties encountered and how these were overcome (see page 13 of the extended essay guide). The concluding interview (viva voce) may provide useful information. These comments can help the examiner award a level for criterion K (holistic judgment). Do not comment on any adverse personal circumstances that may have affected the candidate. If the amount of time spent with the candidate was zero, you must explain this, in particular how it was then possible to authenticate the essay as the candidate's own work. You may attach an additional sheet if there is insufficient space here.

UNDERTOOK HIS EXTENDED ESSAY WITH A VIEW TO INVESTIGATING AN ENVIRONMENTAL ASPECT THAT INCLUDED AREAS OF ANOTHER OF HIS PREFERRED SUBJECTS - PHYSICS. HE WORKED INDEPENTLY ON THE PLANNING OF HIS INVESTIGATION AND CHOSING THE CALCULATOR UTILISED DURING HIS WORK. WHERE TIME AND WORD LIMITS APPLIED PRESSURE HE RESPONDED WELL, USING HIS 'IMAGINARY' HOUSES AS A GOOD TIME SAVING ALTERNATIVE THAT STILL GIVES VIABLE DATA TOWARDS INVESTIGATING HIS INDEPENT VARIABLE. IN THE VIVA VOCE HE CITED WORKS REFERRED TO AND SHOWED GOOD KNOWLEDGE OF A MUCH BROADER RESEARCH BASE. PARTICULAR INSIGHT WAS ALSO SHOWN AS EUGENIO RECOGNISED THAT THIS STUDY WOULD FORM A GOOD BASIS FOR A MORE INDEPTH LOOK AT THE ASPECTS FOUND AS IMPORTANT, SUCH AS WINDOW SIZE/ WINDOW TECHNOLOGY.

This declaration must be signed by the supervisor; otherwise a mark of zero will be issued.

I have read the final version of the extended essay that will be submitted to the examiner.

To the best of my knowledge, the extended essay is the authentic work of the candidate.

As per the section entitled "Responsibilities of the Supervisor" in the EE guide, the recommended number of hours spent with candidates is between 3 and 5 hours. Schools will be contacted when the number of hours is left blank, or where O hours are stated and there lacks an explanation. Schools will also be contacted in the event that number of hours spent is significantly excessive compared to the recommendation.

I spent [3] hours with the candidate discussing the progress of the extended essay.

Supervisor's signature: ______________________ Date: 18.12.14

Assessment form (for examiner use only)

Candidate session number	

Criteria	Achievement level: Examiner 1	maximum	Examiner 2	maximum	Examiner 3
A research question	1	2		2	
B introduction	1	2		2	
C investigation	2	4		4	
D knowledge and understanding	2	4		4	
E reasoned argument	2	4		4	
F analysis and evaluation	2	4		4	
G use of subject language	2	4		4	
H conclusion	1	2		2	
I formal presentation	3	4		4	
J abstract	1	2		2	
K holistic judgment	2	4		4	
Total out of 36	19				

Name of examiner 1: ________ Examiner number: ______________
(CAPITAL letters)

Name of examiner 2: ______________________________ Examiner number: ______________
(CAPITAL letters)

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WHAT TYPE OF HOUSING SHOULD ROME BUILD?

May 2015

Subject: Environmental Systems and Societies

Word count: 3869

ABSTRACT

This essay seeks to answer the question, **what type of housing should Rome build to fulfil the needs of its population whilst working towards sustainability?** It investigates the energy efficiency of different types of buildings, with an eye to ascertain the type best suited to house Rome's growing population at minimal environmental costs. The research involves collecting detailed data on a sample of seven houses, including two (middle) flats, three detached houses, and two bungalows. Each of these actual houses was then used to generate two imaginary houses, of the other types, with otherwise identical characteristics. These twenty-one different houses were then analysed using an energy efficiency calculator. In general, the middle flats performed best, the bungalows worst, both as to overall efficiency and as to CO_2 emissions per unit volume; efficiency was also negatively correlated with the age of the house and with that of its heating plant, while the indoor temperature seemed to be a relatively minor consideration. In general, the results reveal the impact of technical progress in heating plants and building materials. The type of house appears to determine efficiency primarily as a function of the exposed area per unit volume; the latter is clearly highest for bungalows, and least for middle flats, which are naturally insulated, on most sides, by the surrounding units. These results suggest that the energy consumption of the residential structures for Rome's growing population will be minimized by the construction of apartment buildings; and since these can develop in height, they also minimize the attendant loss of urban green space.

Word count: 259

TABLE OF CONTENTS

INTRODUCTION

Pollution is one of the current century's most discussed topics. The world is becoming more and more sensitive to the issue, most effectively through education. I myself was soon taught the importance of respecting and protecting the environment, and over the years I developed a strong interest in environmental issues.

Contamination of the environment because of the emission of chemical substances has increased drastically with many tangible, adverse consequences such as ozone layer depletion, acid rain, habitat degradation, and damage to human health. Perhaps the most serious consequence of pollution, and specifically the emission of greenhouses gases (such as CO_2), is global warming, with the attendant change in climate, rise in sea level, and flooding of now densely populated low-lying coastal areas; but the connection between pollution and climate change is still disputed.[1]

The first cause of most forms of pollution, especially water, air, and land pollution, is the production of energy.

How much do human living standards affect the emission of energy, and what are we doing about it? A UK public document points out that "40% of UK's energy consumption and carbon emissions come from the way our buildings are lit, heated and used"[2]. Housing is the most common type of building. Our well-lit, cosy rooms pollute on a grand scale, no less than industry or transportation: a surprising fact, especially in the context of a developed country, with the necessary funds and technologies to avoid it.

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[1] Environmental System and Societies Course Companion J. Rutherford –Chapter 7-.

[2] https://www.gov.uk/government/policies/improving-the-energy-efficiency-of-buildings-and-using-planning-to-protect-the-environment/supporting-pages/energy-performance-of-buildings 18/10/2014

The best way to analyse buildings' environmental impact is by measuring their energy efficiency. Something is more energy efficient if it delivers more services for the same energy input, or the same services for less energy input.[3] Improving energy efficiency is therefore a way of managing and restraining the growth of energy consumption while maintaining living standards. Indeed, it is the only practical way, as we cannot realistically reduce the number of houses there are; to reduce pollution we can only work on quality and not on quantity.

This essay focuses on the energy efficiency of residential buildings in my home city, Rome, the capital of a country economically and technologically very close to the United Kingdom. Rome's own population is expected to keep growing over the next few decades, even if at falling rates (below, Figure 2). **What type of housing should Rome build to fulfil the needs of its population whilst working towards sustainability?** To identify the type of structure Rome should build for its population the analysis will focus on the characteristics of different types of buildings, and the relation of energy consumption to their occupants' habits and living standards.

In particular, I will compare the structure and related energy consumption of three different types of buildings: detached house, bungalow, and middle flat. I will seek the answer to three questions:

a) what is the difference between the energy efficiency of the buildings?

b) if present, why does such difference occur?

c) which type of building is, therefore, best suited to Rome's growing population?

[3] http://www.iea.org/topics/energyefficiency/ 18/10/2014

BACKGROUND INFORMATION

Rome

The province of Rome has a surface area of 5.352 Km^2 and a population of more than 4.000.000; it is the most populated Italian province[4]. Rome was also the most polluted of the 17 cities that took part at the "sootfreecities" study.[5] On the other hand, Rome boasts 45,6 km^2 of urban "green space", in absolute terms more than any other Italian city.[6] Rome's buildings are located mostly (79%) in residential areas.

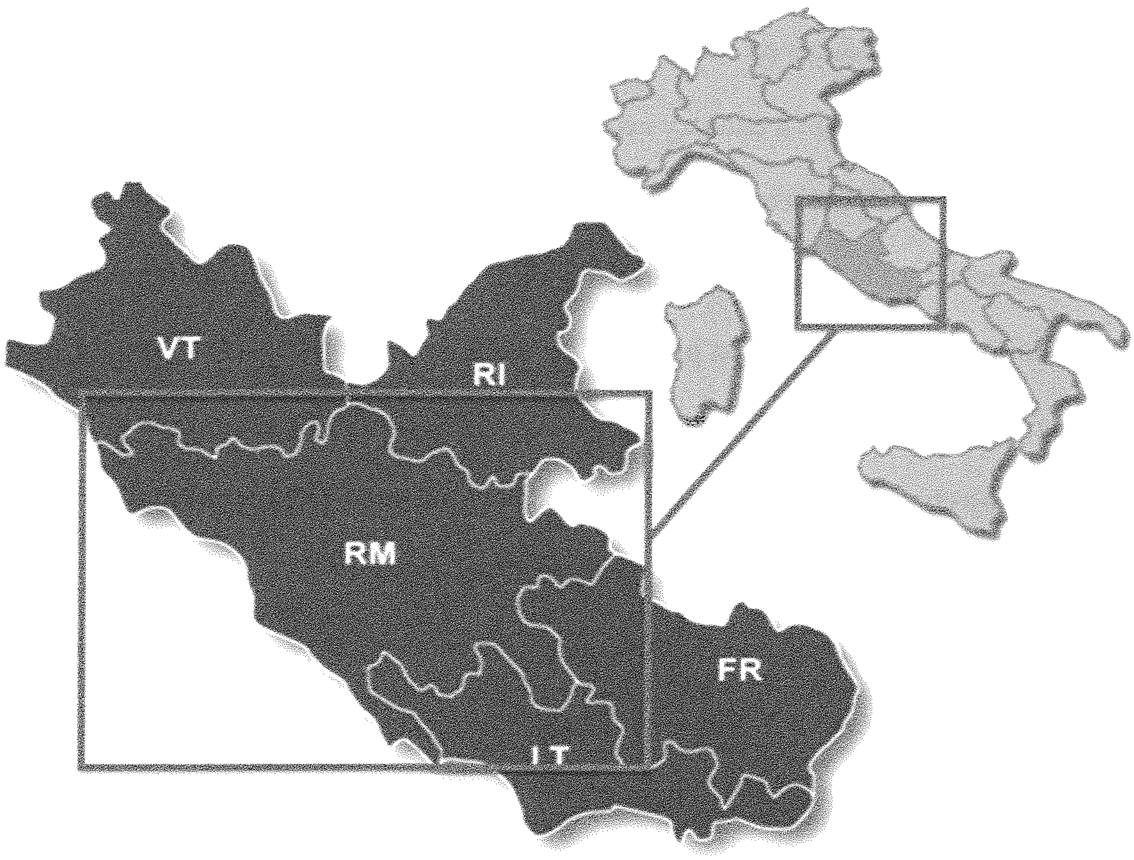


Figure 1: Map of Rome's province and its location in Italy[7] [8]

[4] http://protezionecivile.provincia.roma.it/portale/default.asp?nPagina=premessa 19/10/2014
[5] http://sootfreecities.eu/city 19/10/2014
[6] Verde urbano - 04_apr_2013 - Testo integrale 20/10/2014
[7] http://www.immagineimmobiliare.com/affitto/index.php?option=com_content&view=article&id=11&Itemid=26 25/10/2014
[8] http://casa.contributi.it/contributi-casa-lazio 27/10/2014

Trends in population

The demand for new buildings is driven in the first instance by population growth. Rome's population increased very rapidly from the later nineteenth century on (in essence, since 1870, when the capital of the Papal States became the capital of Italy). That growth is now abating, but is not expected to end in the near future.

Graph 1

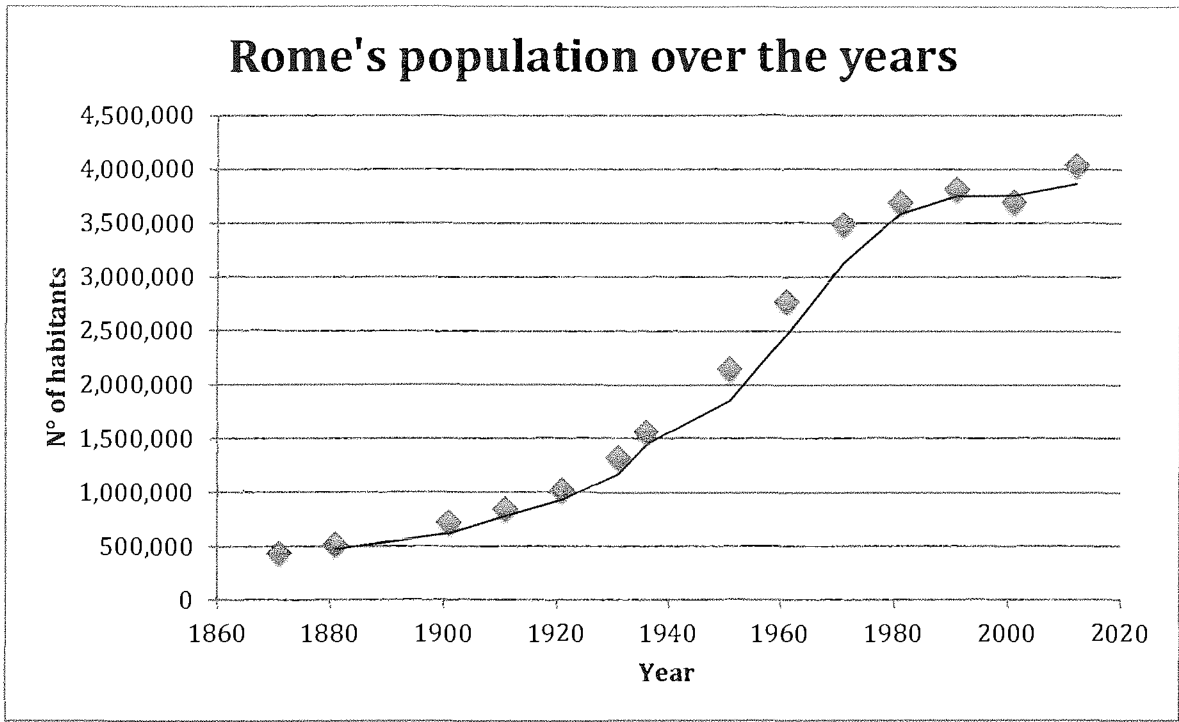


Figure 2: The evolution of the number of Rome's inhabitants

Trends in impervious surface

Impervious surfaces (artificial structures such as pavements, roads etc…) are damaging for the environment:

- "The pavement materials seal the soil surface, eliminating rainwater infiltration and natural groundwater recharge. From a recent article in the Seattle Times: 'While urban areas cover only 3% of the U.S., it is estimated that their runoff is the primary source of pollution in 13% of rivers, 18% of lakes and 32% of estuaries.' Polluted runoff can have many negative effects on fish, animals, plants and people.
- Impervious surfaces collect solar heat in their dense mass. When the heat is released, it raises air temperatures, producing urban 'heat islands', and increasing [summertime] energy consumption in buildings. The warm runoff from impervious surfaces reduces dissolved oxygen in stream water, making life difficult in aquatic ecosystems.

Impervious pavements deprive tree roots of aeration, eliminating the 'urban forest' and the canopy shade that would otherwise moderate urban climate. Because impervious surfaces displace living vegetation, they reduce ecological productivity, and interrupt atmospheric carbon cycling."[9]

[9] http://en.wikipedia.org/wiki/Impervious_surface 01/11/2014

In the province of Rome, the available data suggest a mild but unfavourable trend, with the impervious share of the total surface rising from 11.5% in 1990 to 11.7% in 2000.[10] The trend is expected to continue (figure 3); to identify the type of building best suited to sustainable growth its contribution to the increase in impervious surface must be kept in mind.

Graph 2

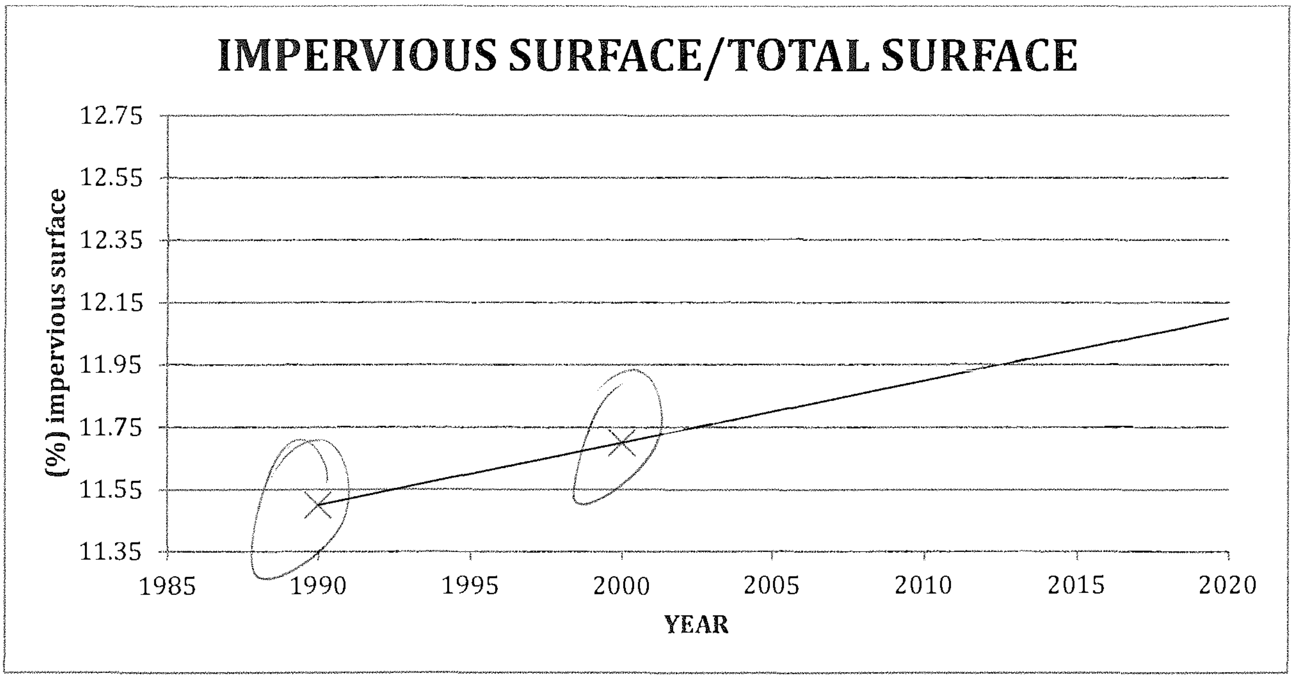


Figure 3: Trend in the share of the impervious surface in the province of Rome

[10] http://www.areeurbane.isprambiente.it/it/pubblicazioni/rapporti/iii-rapporto/iii-rapporto-capitoli/addendum/49_Impermeabilizzazione%20e%20consumo%20suoli%20aree%20urbane%20INTEGRAL.pdf (02/10/2014)

Building types

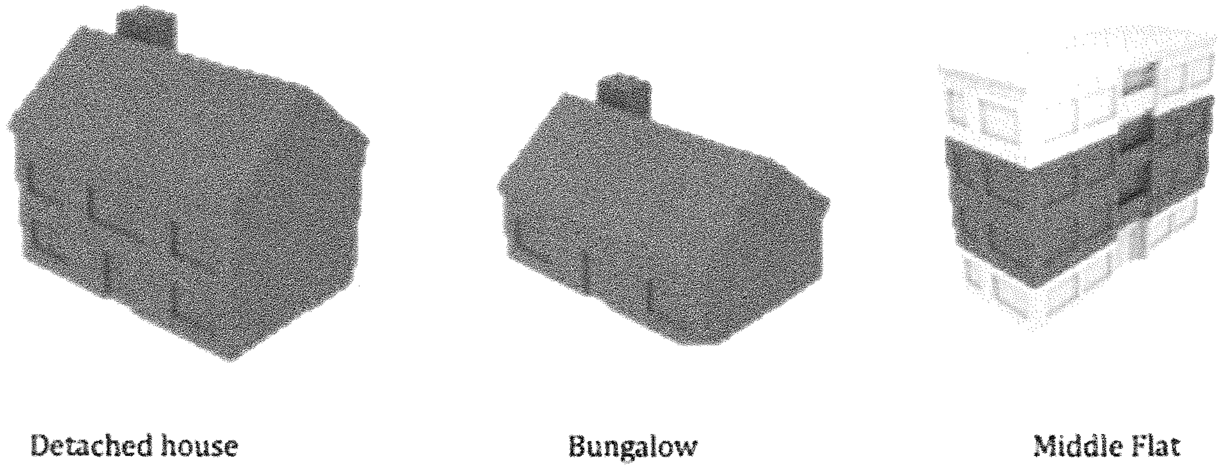


Figure 4: 3D models of the three types of housing analysed in this essay[11]

In order to answer the question –What type of housing should Rome build to fulfil the needs of its population whilst working towards sustainability? - I will analyse 7 different buildings. All are within Rome's territory and are located in residential areas. Two are bungalows, two middle flats, and three detached houses.

In 2012 the types of housing most diffused in countries of the European union were apartments (41.6%) and detached houses (34.0%)[12]. I could not find comparable information for the province of Rome (or for Italy); however, observation suggests that detached houses and apartments predominate within Rome's territory as well, with bungalows dominating the residual.

[11] Images are from http://energyefficiency.johnlewis.info/Start.aspx 10/11/2014
[12] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Housing_statistics 08/11/2014

To isolate the effects of the type of building, each one in my sample was used to generate two more imaginary buildings with the same other characteristics: for example, if I had a 300-square meter middle apartment with brick walls, I imagined a bungalow, and a detached house, of similar planform area and materials. The energy efficiency of all three, as revealed by the appropriate calculator (described below), accordingly varies only by type of house, and accordingly isolates the differences of interest here.

Legislation on energy efficiency

A governmental website published the following article regarding incentives on the energy efficiency of buildings. The G.U. ("Gazzetta Ufficiale") is the official magazine of the Italian government.

Following the G.U. n ° 302 of 12/27/2013 of 27 December 2013 Law No. 147 (Stability Law 2014), in the case of energy efficiency measures, deductions can be extended to the extent of 65%, for costs incurred by the June 6, 2013 to December 31, 2014 and by 50% for expenditure incurred from 1 January 2015 to 31 December 2015. In the case of improvements relating to the common areas of apartment buildings or affecting all units of a condominium, these deductions are extended to the extent of 65%, for costs incurred from 6 June 2013 to 30 June 2015 and by 50% for expenses incurred from 1 July 2015 to 30 June 2016.[13]

The following changes are considered energy efficiency measures:

- upgrading the energy efficiency of existing buildings
- Building envelope (walls, windows, including windows, on existing buildings)
- installation of solar panels
- replacement of the winter heating

This legislation shows that the government is aware of the impact of relatively inefficient buildings on the environment.

[13] http://efficienzaenergetica.acs.enea.it 20/10/14

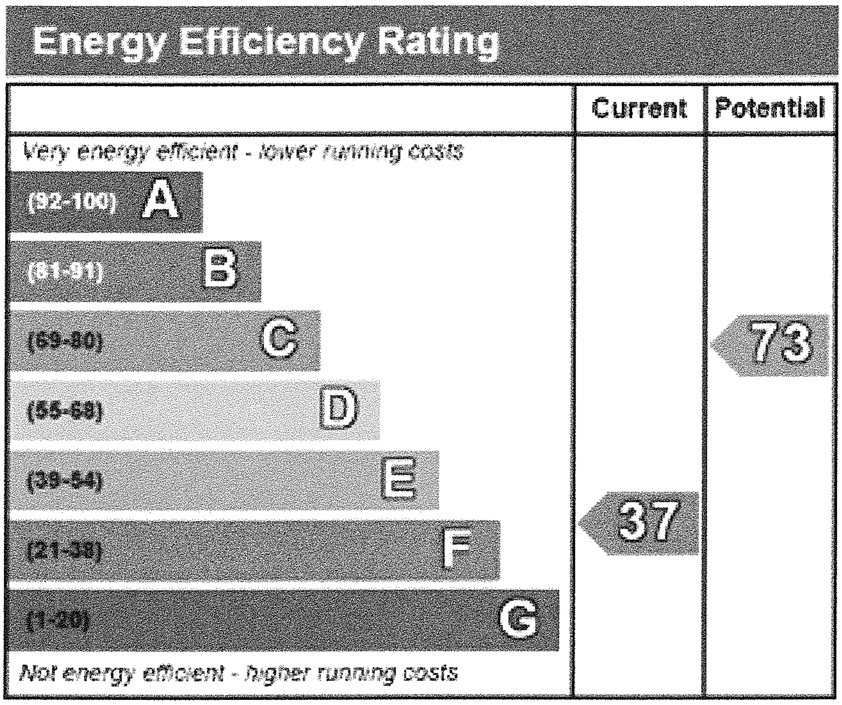
Energy class

The building's energy class is documented by an Energy performance certificate (EPC). The latter consists of: a multi-coloured sticker indicating the energy efficiency of the building, rating it from A (very efficient) to G (inefficient). EPCs let the person who will use the building know how costly it will be to heat and light, and what its carbon dioxide emissions are likely to be.[14]

The rating scale is colour coded from A to G:

- A (Dark green) is highly efficient
- G (Red) is low efficiency

Most homes appear around grade D, this is the average.[15]



[16]

[14] http://www.energysavingtrust.org.uk/domestic/content/energy-performance-certificates 25/10/2014
[15] http://www.uswitch.com/solar-panels/guides/energy-performance-certificate/ 25/10/2014
[16] http://cms.walsall.gov.uk/index/energy_performance_certificates-4.htm 25/10/2014

METHODOLOGY

Primary data

A questionnaire will be given out to the owners of 3 different types of building (two flats, three detached houses, two bungalows), collecting information on the characteristics of the houses.

The buildings will vary in size and age in order to have a wider view on the topic.

The information retrieved was used to calculate the energy efficiency of each building through an online energy efficiency calculator (see below, "chose a calculator", for further details).

Secondary data

The data from each type of building will be used to calculate the energy efficiency of two hypothetical buildings with the same characteristics as the one in the survey (e.g., age, planform area, window type, etc ...) but of a different type (e.g., bungalow instead of flat ...).

The comparison of the different energy efficiencies of each building type made use of both their energy classes (a qualitative representation of their energy efficiencies) and of their carbon dioxide emissions (a quantitative value strictly related to their energy efficiency[17]).

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[17] Sustainable Materials -with both eyes open- J. Allwood J. Cullen pg. 23

The trend in population and information about the legislation regarding energy efficiency was collected through secondary data from a wide range of sources. These data helped better understand Rome's society. Secondary data will also be used to analyse which feature of the buildings have the most impact on their energy efficiency.

The survey (primary data) and the calculator (processing primary data) will be used to explain what the differences in the energy efficiencies of the different types of buildings are, whereas secondary data will help explaining why those differences occur.

Websites and scientific papers are used as sources of information, and are referred to as appropriate. To ensure reliability the websites are typically official ones, either of governments or of well-known organisations. The printed sources are from reliable authors expert in the topic at hand.

Research on Rome

I have researched Rome's new house necessity by looking at the trend in the population that lives within Rome's province.

I have researched "urban green space available in Rome"

I have researched legislation promoting "green buildings".

Choice of calculator

The calculation of energy efficiency required choosing an energy efficiency calculator with the desired characteristics, notably that it be unbiased, and that it yield a numerical (or scalar) value for the energy efficiency of the buildings.

An extended survey suggested that the best available calculators are the following:

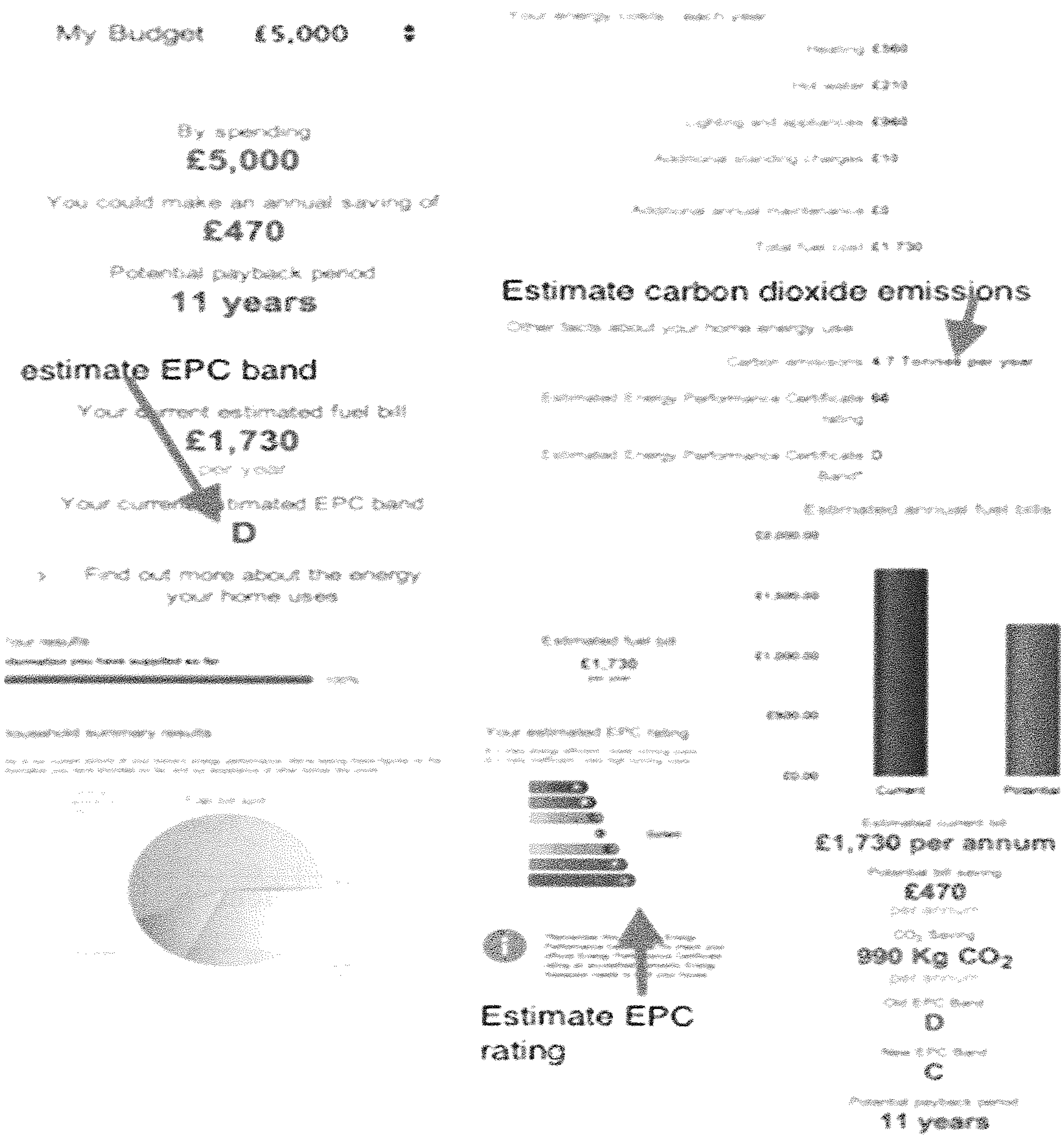
- http://www.makeyourbuildingswork.com/energy-efficiency-calculator/
- http://energy.gov/eere/femp/energy-and-cost-savings-calculators-energy-efficient-products
- http://energyefficiency.johnlewis.info/Default.aspx?reason=logout

The first remained, for present purposes, less than ideal. First, it was designed for buildings located in the USA, and there was little chance of finding a US state comparable to Italy (with respect both to climate and to legislation on emissions and building materials). Second, it was calibrated only for working buildings and not for private residences. Third, and more importantly, the calculator requires very few inputs, suggesting that it excludes important sources of variation.

The second, on the other hand, asks for information that is not easy to retrieve. Moreover, it does not actually measure the building's energy efficiency, but rather limits itself to showing the potential (money) saving that could be achieved by replacing the appliances and products of the house with more efficient ones.

The third alone appears well-suited to the present analysis. It asks for detailed information and it focuses on the characteristics of the building. In addition, as an answer, it gives not only the energy class of the building but also, usefully, an estimate of the tons of CO_2 produced per year by the building and the potential savings that could be achieved with a given budget.

The calculator I chose gives an answer through the following screens[18]:



- [18] All the screens were taken from http://energyefficiency.johnlewis.info/Default.aspx?reason=logout

RESULTS AND ANALYSIS

Results from questionnaire

Building type

The survey (reproduced as an appendix) was given to 7 people all of whom owned one of the three types of building to be investigated. The buildings were carefully chosen in order to obtain a wide range of data. The raw data are contained in the appendix; those that served as inputs for the calculator are indicated there.

The raw data thus collected yielded the following results. The original (actual) house is shaded, the other two are not; the "best" houses are in the highest energy class (A) and emit the lowest tonnage of CO_2.

ENERGY CLASS Table 1

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7
Detached house	C	E	E	F	E	D	D
Bungalow	D	E	E	F	G	E	D
Middle flat	B	C	C	C	F	C	B

Figure 5: Energy efficiency class of the buildings that took part to the survey

TONNES OF CO_2 Table 2

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7
Detached house	4.5	6.7	6.0	5.5	10.2	7.8	4.5
Bungalow	4.7	6.1	3.7	5.9	9.9	8.0	4.0
Middle flat	4.1	3.9	2.8	1.9	7.4	5.4	2.6

Figure 6: CO_2 emissions of the buildings that took part to the survey.

Graph 3

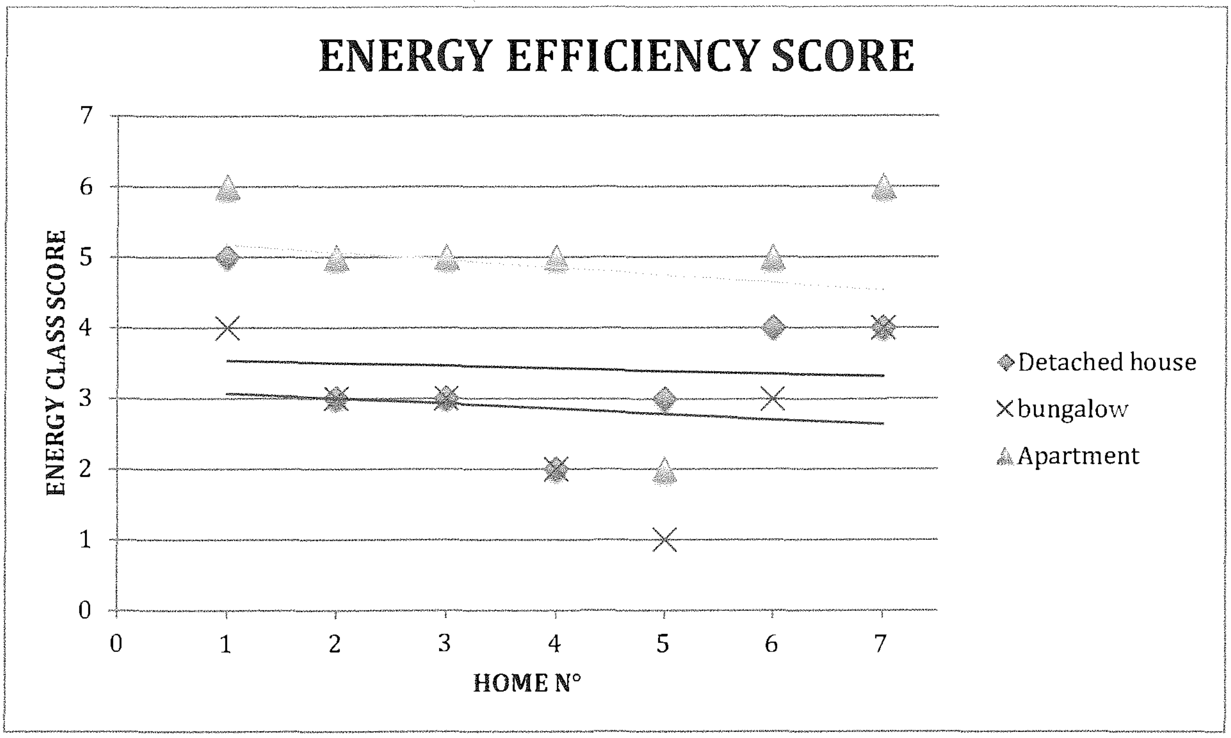


Figure 7: Energy efficiency class of the buildings that took part to the survey.

Table 3

SCORING KEY:		
Energy Efficiency Class		Energy Efficiency Score
A	=	7
B	=	6
C	=	5
D	=	4
E	=	3
F	=	2
G	=	1

Figure 8: Key to energy efficiency score.

To calculate the total energy efficiency score for each type of building, the energy efficiency scores (of each type of building) were added together to give a numerical value for the efficiency of the buildings (the higher the score the more efficient the building).

Table 4

TYPE OF BUILDING	TOTAL ENERGY EFFICIENCY SCORE
Detached house	24
Bungalow	20
Middle flat	34

Figure 9: Total energy efficiency score for each type of building in the survey.

Graph 4

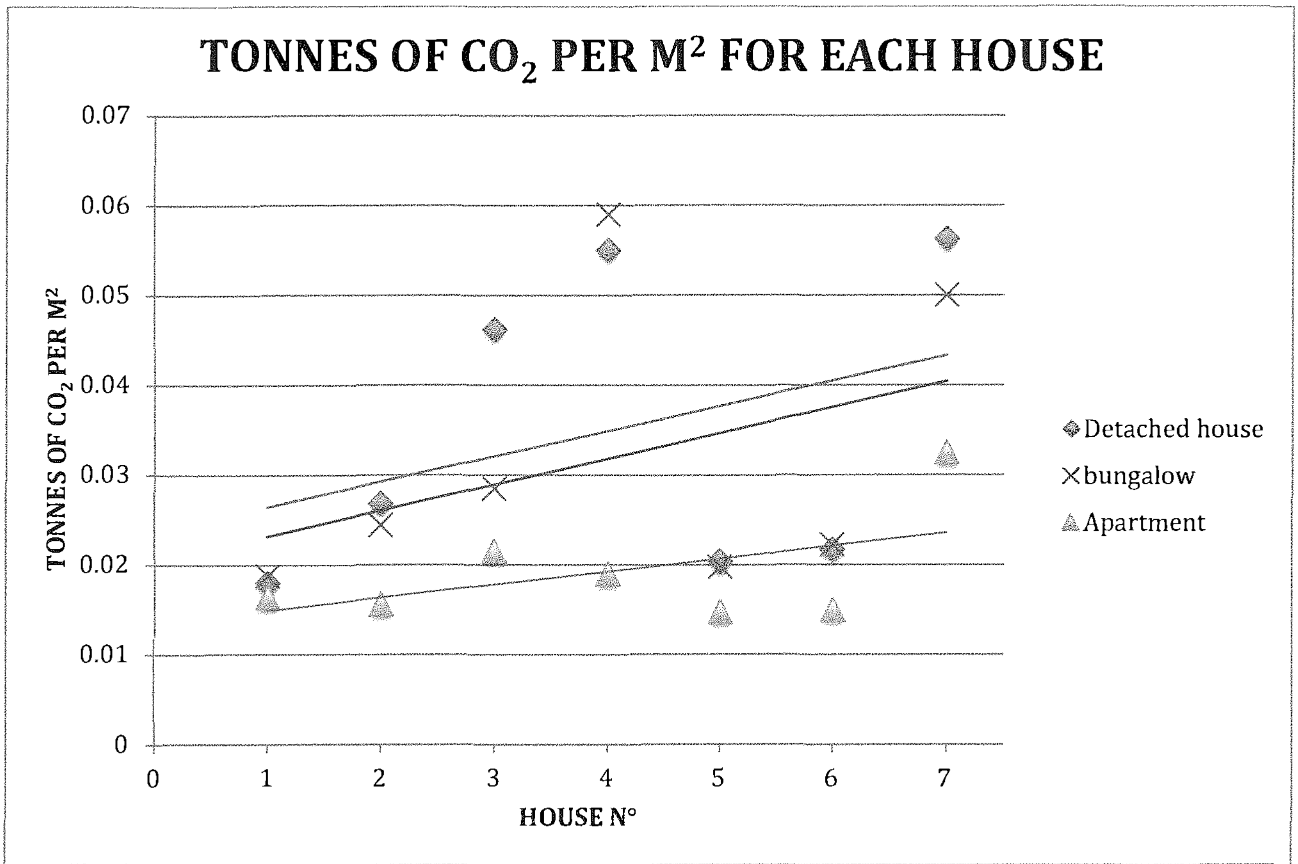


Figure 10: CO_2 emissions of the buildings in the survey.

To calculate the average for each type of building, the CO_2 emissions per m^2 (of each type of building) were added together and then divided by 7.

Table 5

Type of housing	**AVERAGE CO_2 per m^2**
Detached house	0,0349
Bungalow	0,0318
Middle flat	0,0193

Figure 11: table showing the average CO_2 per m^2 for each type of building in the survey.

Factors other than building type

The average CO_2 emission was calculated by adding up all the CO_2 emission from each house for detached house, bungalow and middle flat

Table 6

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7
CO_2 emissions (tonnes) Detached house	4,5	6,7	6	5,5	10,2	7,8	4,5
CO_2 emissions (tonnes) Bungalow	4,7	6,1	3,7	5,9	9,9	8	4
CO_2 emissions (tonnes) Apartment	4,1	3,9	2,8	1,9	7,4	5,4	2,6
Average CO_2 emissions of each house (tonnes)	4,43	5,57	4,17	4,43	9,17	7,07	3,7
Year of construction	2005	1940	1970	1990	1964	1985	2011
Age	9	74	44	24	50	29	3
Planform (m^2)	250	250	130	100	500	360	80
Heating system age (years)	9	5	2	4	15	9	2
Indoor winter temperature (°C)	22	19	23	21	19	21	22
N° of external doors	2	5	2	5	8	6	1
Total window area (m^2)	32	50	26	20	100	37	9

Figure 12: Factors that might affect the CO_2 emissions of the buildings

I will compare these factors using the average data for each house. By doing so I will avoid results being influenced by the type of housing and I will be able to evaluate the influence that each characteristic has on the energy efficiency of the building.

Graph 5

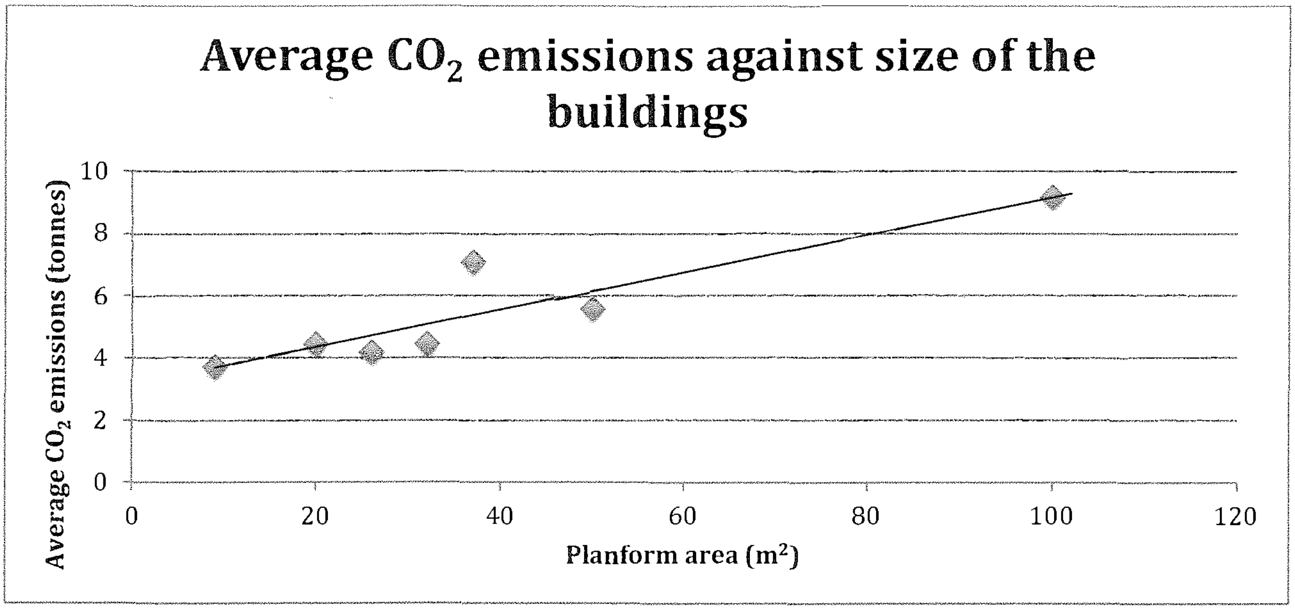


Figure 13: Relation between CO_2 emissions and the planform area of the house.

Graph 6

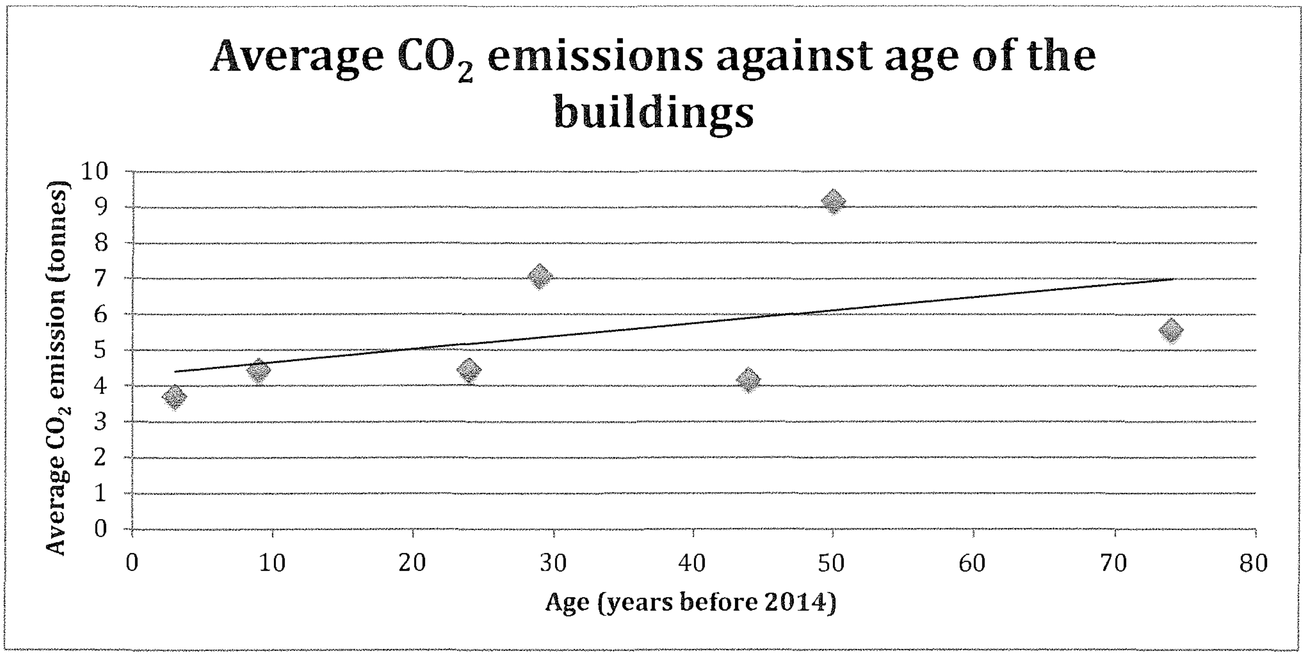


Figure 14: Relation between CO_2 emissions and the age of the house.

Graph 7

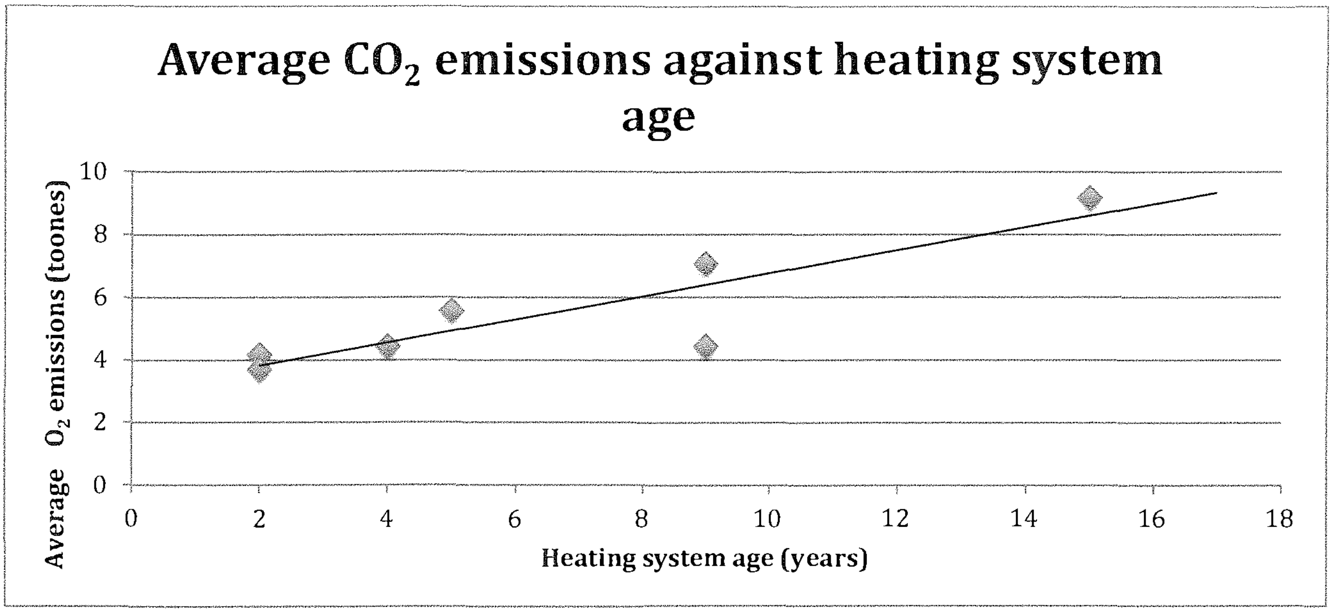


Figure 15: Relation between CO_2 emissions and the age of the heating system.

Graph 8

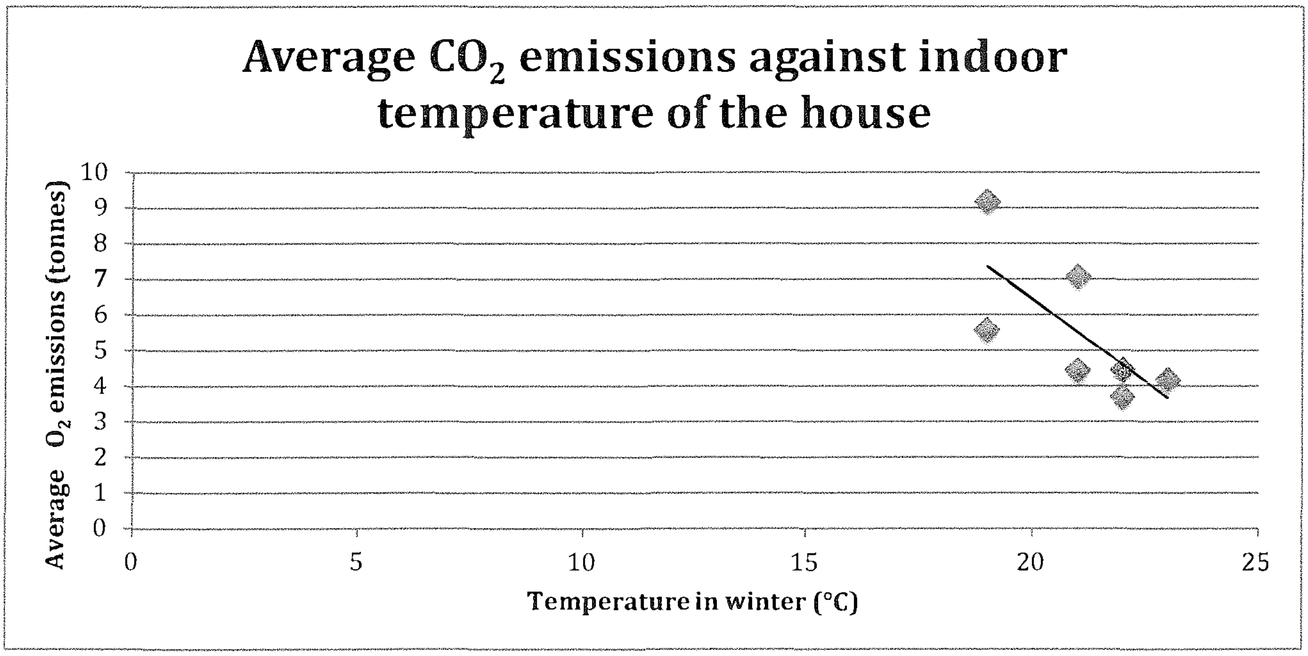


Figure 16: Relation between CO_2 emissions and the indoor temperature maintained in winter

Graph 9

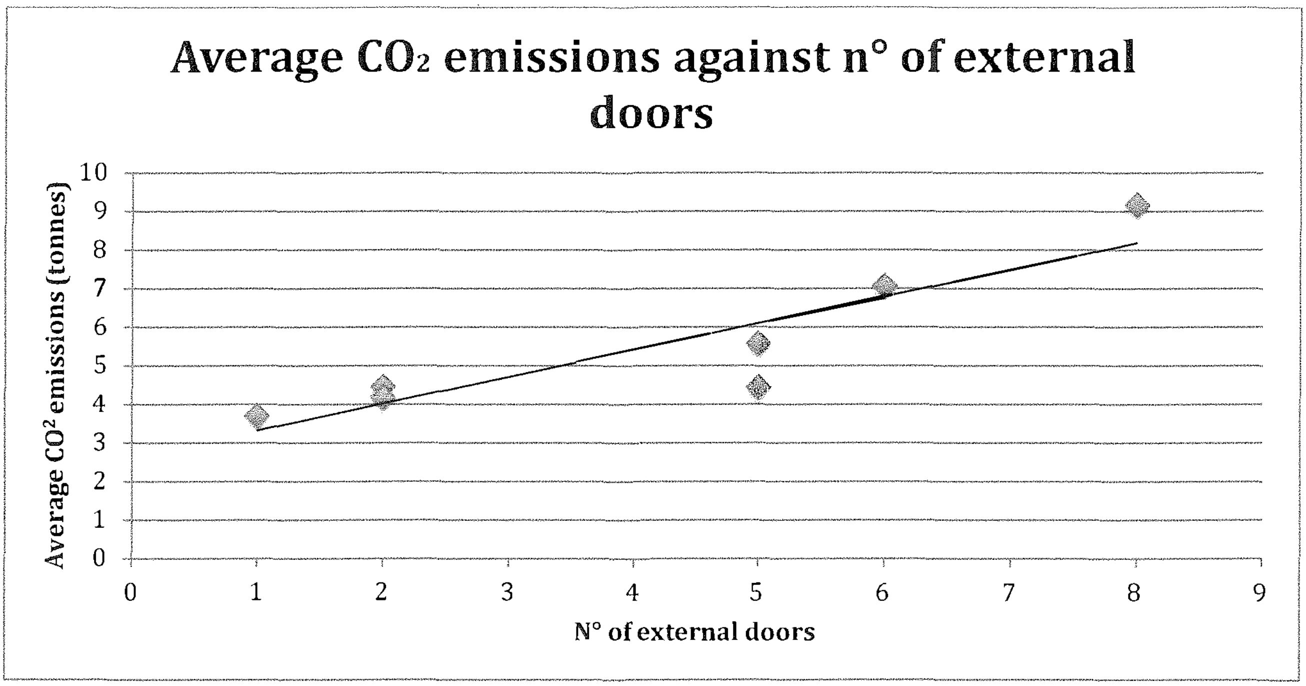


Figure 17: Relation between CO_2 emissions and the number of external doors a house has.

Graph 10

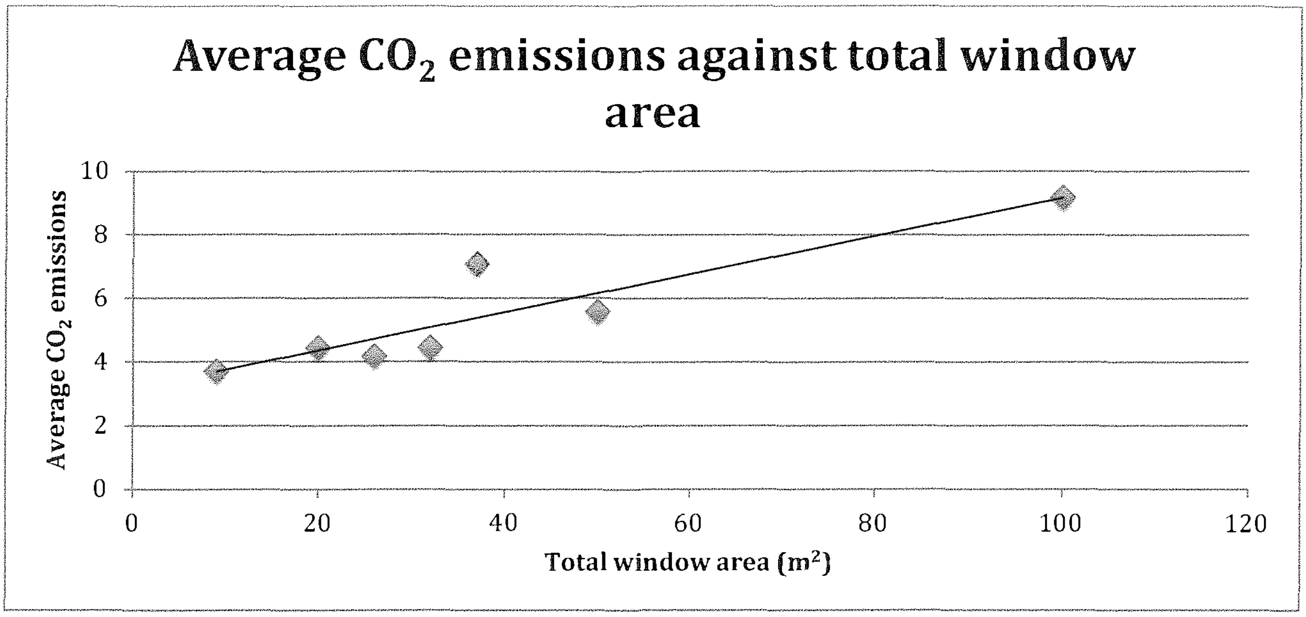


Figure 18: Relation between CO_2 emissions and the window area of a house.

Analysis of responses

Building type

Figures 9 and 7 show that the type of building which has the highest energy efficiency score, and therefore the best average energy efficiency, is the middle flat (with a score of 34), followed by the detached house (24) and by the bungalow (with only 20 points).

The trend lines in figure 7 show that there is a net distinction in the energy efficiencies of the different type of buildings, and reinforce the concept that middle flats are much more energy efficient than bungalows and detached house.[19]

Figure 10 and figure 11 also suggest that the middle flat is the most green building; however they also illustrate that detached houses emit more tonnes of CO_2 than bungalows. This may seem to contrast with the previous suggestion that detached house were more energy efficient than bungalows. So, how can a house with a better energy efficiency emit more CO_2 than one with a lower energy efficiency?

The answer is simple: a detached house with the same planform area of a bungalow (e.g., 200m^2) has, in fact, a volume twice as big as the one of the bungalow. This is due to the fact that a detached house is, at least, a two-story building whereas a bungalow is a one-story building. It is now obvious that the energy consumed by the detached house is used to heat or cool an environment that is twice as big as the one of the bungalow. To make it clear, we can analyse the CO_2 emissions per m^2 of the

[19] Since the houses on the *x* axis are in random order, the slopes of the trend lines in figure 7 (and 10) are not meaningful; what remains significant is the relative *position* of the trend lines.

bungalow and of the detached house (0.0318 and 0.0349 tonnes respectively) and translate them into CO_2 emissions per m^3. Assuming that each store has a height of 1m (which is unrealistic but it makes calculations simpler without changing the results) and that the detached house has two storeys, we can now find a numerical value for the CO_2 emissions per m^3.

For the bungalow: $0.0318/1= 0.0318$ tonnes per m^3

For the detached house: $0.0349/2= 0.01745 \approx 0.0175$ tonnes per m^3

We can now see that effectively, the carbon dioxide emissions per unit volume are smaller in the detached house than in the bungalow.

Obviously this is a simplification, and, even if CO_2 emissions and energy efficiency are strongly related, they are not the same thing. However, this can help understand why the detached house has a better energy efficiency than the bungalow even if it emits more CO_2 per m^2 of footprint.

Factors other than building type

Most of the factors will be compared using the average CO_2 emissions or CO_2 emissions per m^2 as a reference since they are a good indicator of the energy consumption of the house.

Figure 13 shows that there is a positive correlation between the planform area of the building and their CO_2 emissions. This is because more fuel (energy) is needed to heat or cool a bigger environment.

Figure 14 also shows a positive correlation but this time is between the age of the building and its CO_2 emissions. This is probably due to the fact that when the older houses were built, most of the technologies and eco-friendly materials that are used nowadays were not available or more expensive. Furthermore, in the past, there was less awareness about the environmental problems caused by buildings.

Figure 15 suggests that the older the heating system the less efficient the building is. The explanation is similar to the one given for figure 14. Higher fuel prices and growing environmental awareness have produced significant progress in heating and cooling technology; the newer systems are inherently more efficient than the older ones.

Figure 16, surprisingly, conveys that the CO_2 emissions of the building are not directly dependent on the temperature at which the house is kept during winter. This does not imply that this factor doesn't have any negative repercussions on the energy consumption of a building, because, obviously, the warmer you keep an environment, the more energy you need to maintain that temperature. However these results do suggest that this factor is secondary to other aspects of the building such as age and planform area.

Figures 17 and 18 suggest that the higher the number of windows and doors, the more CO_2 is released to maintain a constant environment in the house. This is due to the fact that doors and windows have a lower insulating capacity than walls: the larger the number of windows and doors, the more heat will be exchanged with the surroundings and, correspondingly, the greater the energy requirement of the building.

DISCUSSION

A consistent pattern that emerges shows that apartments have -- in general -- a better energy efficiency than detached houses, which in turn have a better energy ranking than bungalows.

This is due to the fact that apartments (especially middle floor, as the one tested by my survey) have a lower area exposed to the surroundings since they are placed above and below also-heated rooms.

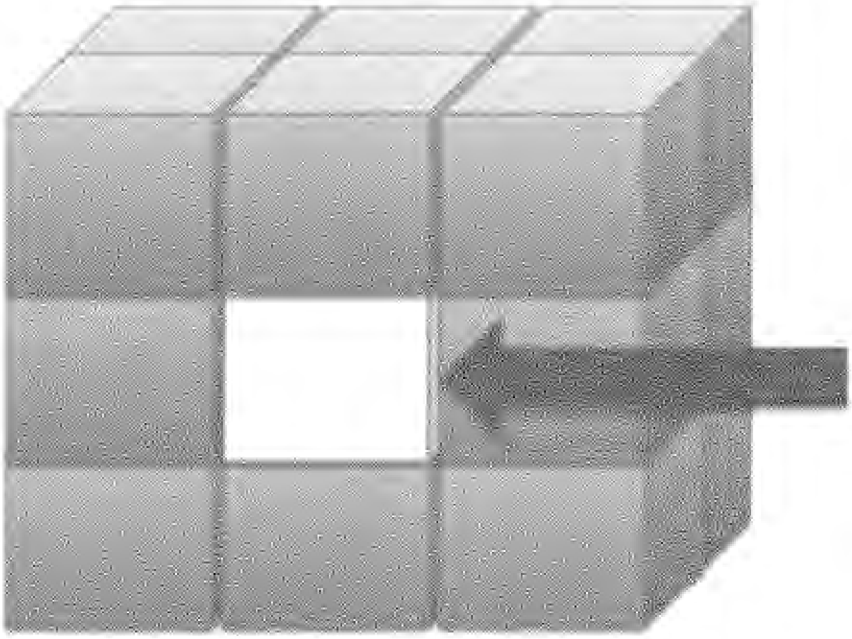


Figure 19: Model of a middle flat

The apartment in yellow is surrounded on 5 sides (out of 6) by heated rooms. This implies that the surface area through which the house can lose heat to the surroundings is reduced by a factor of 5/6 with respect to an isolated house suspended in space, or 4/5 if we consider the ground as itself an insulating surface.

This means that middle flats are "naturally" insulated and obtain by virtue of their structure what bungalows and detached houses obtain by artificial insulation.
To explain the difference in energy efficiency of a detached house and a bungalow we have to analyse the ratio of the volume of the building to the surface area exposed to the surroundings.

Using another simplified model helps to explain this fact.

Figure 20: Models of bungalow and detached house.

Assuming that the dimensions of each parallelepiped are (5*2*2m) then the volume of the bungalow will be $20m^3$ with a total SA of $48m^2$ and therefore its ratio volume to SA will be 20/48=0,417. On the other side the volume of the bungalow will be $40m^3$ and its SA will be $76m^2$. As a result the ratio will be 40/76=0,526.

This simply means that, in the bungalow, more SA of the building is exposed to the surroundings per unit volume heated. And, since the rate of heat transfer is directly proportional to the surface area through which the heat is being conducted[20], it follows that the detached house, with two storeys, is naturally better insulated than the bungalow, with one.

[20] http://www.physicsclassroom.com/class/thermalP/Lesson-1/Rates-of-Heat-Transfer 29/10/2014

EVALUATION

The analysis was in many ways limited. Firstly, the number of buildings in the sample was small, and a bigger sample (a minimum of 15 buildings) would have made the results more reliable.

Secondly, the analysis of the factors influencing the energy efficiency of the buildings did not consider that some factors were strongly related to each other. For example a large building is likely to have a large window area in the same way a building with a small window area is likely to be small. Because these two factors go hand in hand it was difficult to determine whether energy efficiency was more affected by the planform area of the building or by its window area. Some background research on the various factors would have been useful to understand better the effects of each factor.

Last, but not least, the models used to explain why each factor had such an influence were no doubt simplistic, and did not provide an in-depth explanation. A better analysis would have resulted had I brought to bear a greater technical knowledge of the actual determinants of energy consumption, heat transfer, and the like.

CONCLUSION

Housing is a major contributor to energy consumption and pollution and, very possibly, global warming. This essay has examined the energy efficiency of the different structures that can be built to accommodate the growing population of the city of Rome.

My research suggests that Rome should build apartments to fulfil the needs of its population while working towards energy efficiency. This is due to the fact that the majority of apartments are placed on middle flats and are therefore naturally insulated by those that surround them. Moreover, apartment buildings can develop in height and contain a large number of housing units without occupying a large area of ground. This would help reduce the depletion of urban green space, which is one of the biggest problems Rome is facing.

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APPENDIX

Survey Answers

Key: The shaded variables are *not* used by the calculator.

	Home 1	**Home 2**	**Home 3**	**Home 4**	**Home 5**	**Home 6**	**Home 7**
Type of housing	bungalow	detached house	Middle flat	bungalow	Detached house	Detached house	Middle flat
Year of construction	2005	1940	1970	1990	1964	1985	2011
Planform (m^2)	250	250	130	100	500	360	80
N° of bedrooms	3	3	2	2	5	4	2
Gas connection	NO	YES	NO	YES	YES	YES	YES
Chimney adaptable to log stove	YES	YES	NO	YES	NO	YES	NO
Large garden	YES	YES	YES	YES	YES	YES	NO
Significantly exposed to sun and wind	YES	YES	YES	NO	YES	YES	YES
Access to loft	NO	NO	NO	NO	NO	YES	YES
Roof facing South-East or South-West	YES	YES	YES	YES	YES	YES	YES
Heating type	STOVE	CENTRAL HEATING	STOVE	CENTRAL HEATING	GAS	GAS CENTRAL HEATING	GAS CENTRAL HEATING
Main fuel used	PELLET	MAINS GAS	PELLET	GPL	GPL	GAS (METHANE)	GAS (METHANE)

Hot water tank	NO	NO	NO	NO	YES	YES	YES
Heating controls	NO	PROGRAMMER AND ONE ROOM THERMOSTAT	NO	NO	NO	PROGRAMMER AND ONE ROOM THERMOSTAT	PROGRAMMER AND ONE ROOM THERMOSTAT
Heating system age (years)	9	5	2	4	15	9	2
Primary wall type	SOLID BRICK	GRANITE OR WHIN	SOLID BRICK	GRANITE OR WHIN	SOLID BRICK	SOLID BRICK	BRICK CAVITY WALL
Primary wall insulation	As built	As built	As built	As built	As built	As built	As built
Lowest floor type	SOLID FLOOR	SOLID FLOOR	SOLID FLOOR	SOLID FLOOR	SOLID FLOOR	SOLID FLOOR	SUSPENDED TIMBER
Floor insulation	None/unknown	None/unknown	Above a heated room	None/unknown	None/unknown	None/unknown	Above a heated room
Roof type	PITCHED	PITCHED	/	PITCHED	PITCHED	PITCHED	/
Amount of roof insulation	50mm	100mm	None	75mm	75mm	55mm	50mm
How many people live in the house	3	3	2	2	6	4	2
Temperature kept in winter (°C)	22-23	19	23	21	19	21	25
Home heating on typical working day	OUTSIDE WORKING HOURS+LUNCH TIME	DAY+NIGHT	OUTSIDE WORKING HOURS+LUNCH TIME	OUTSIDE WORKING HOURS+LUNCH TIME+NIGHT	DAY+NIGHT	OUTSIDE WORKING HOURS + NIGHT	OUTSIDE WORKING HOURS

Home heating on typical non-working day	ALL DAY AND NIGHT	DAY+NIGHT	ALL DAY	DAY+NIGHT	DAY+NIGHT	OUTSIDE WORKING HOURS+ NIGHT	OUTSIDE WORKING HOURS+ LUNCH TIME
Closed and un-heated rooms	1	2	NO	NO	NO	3	NO
Type of shower	I don't know	I don't know	I don't know	I don't know	I don't know	I don't know	I don't know
N° of showers taken in a week	21	20	14	14	42	28	14
External doors	2	5	2	5	8	6	1
Predominant door type	WOOD, NO GLAZING	WOOD, SIMPLE GLAZING	UPVC DOOR	WOOD, DOUBLE GLAZING	WOOD, NO GLAZING	WOOD NO GLAZING	WOOD DOUBLE GLAZING
Predominant window type	DOUBLE GLAZED, AFTER 2002	DOUBLE GLAZED, BEFORE 2002	DOUBLE GLAZED, BEFORE 2002	DOUBLE GLAZED, BEFORE 2002	DOUBLE GLAZED, BEFORE 2002	DOUBLE GLAZED BEFORE 2002	DOUBLE GLAZED, AFTER 2002
Predominant window frame type	WOOD	WOOD	PVC	METAL	WOOD	METAL	PVC
Approximate percentage used by above window type	100%	100%	100%	100%	100%	94%	100%
Alternative window type	NO	NO	NO	NO	NO	Double glazed after 2002	No
Alternative window frame	NO	NO	NO	NO	NO	METAL	No
Total window area (m2)	32	50	26	20	100	37	9

Photovoltaic	NO	NO	NO	NO	NO	NO	NO
Micro wind turbine	NO	NO	NO	NO	NO	NO	NO
Solar hot water	NO	NO	NO	NO	NO	YES	NO
Rooms with low energy lighting	ALL	ALL	ALL	SOME	SOME	ALL	ALL
Tumble drier	NONE	NONE	NONE	YES	YES	YES	YES
Washing dried in tumble drier/year	0%	0%	0%	25%	10%	75%	10%
Frdges and freezers	4 OR MORE	1	2	1	2	2	1
Fridges	2	1	1	0	0	2	1
Freezers	2	1	1	0	0	0	0
Cooker type	GAS HOB WITH ELECTRIC OVEN (NORMAL 4 HOBS OR FEWER)	GAS HOB WITH ELECTRIC OVEN (BIG 4 HOBS OR MORE)	GAS HOB WITH ELECTRIC OVEN (NORMAL 4 HOBS OR FEWER)	GAS HOB WITH ELECTRIC OVEN (NORMAL 4 HOBS OR FEWER)	GAS HOB WITH OVEN (BIG 4 HOBS OR MORE)	GAS HOB AND ELECTRIC OVEN (BIG 4 HOBS OR MORE)	GAS HOB WITH ELECTRIC OVEN (NORMAL 4 HOBS OR FEWER)
Fuel used by oven and hob	GPL BOTTLE	GPL (MAIN GAS)	GPL (MAIN GAS)	GPL (MAIN GAS)	Large gas tank GPL	GAS (MAIN GAS)	GAS (MAIN GAS)

How much money would you spend to improve your home's energy efficiency and reduce CO_2 emissions? (£)	5000	5000	NOTHING	5000	8000	20000	7000