Energy Performance Evaluation

Tyrrelstown Housing Development Dublin.

For

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1. INTRODUCTION

This report analyses the energy performance of sample apartments at the Tyrrelstown Housing Development in Dublin. The development comprises of the construction of 234 new family homes including both houses and apartments in 2 and 3 storey blocks together with 3 communal welfare facilities including a crèche, community centre, estate management offices and a public park. The site is Northwest of Dublin. A block of apartments have been selected to analyze the energy performance, as it is an increasingly common building typology in Ireland, and at the same time its energy performance and improvement options are generally less studied.

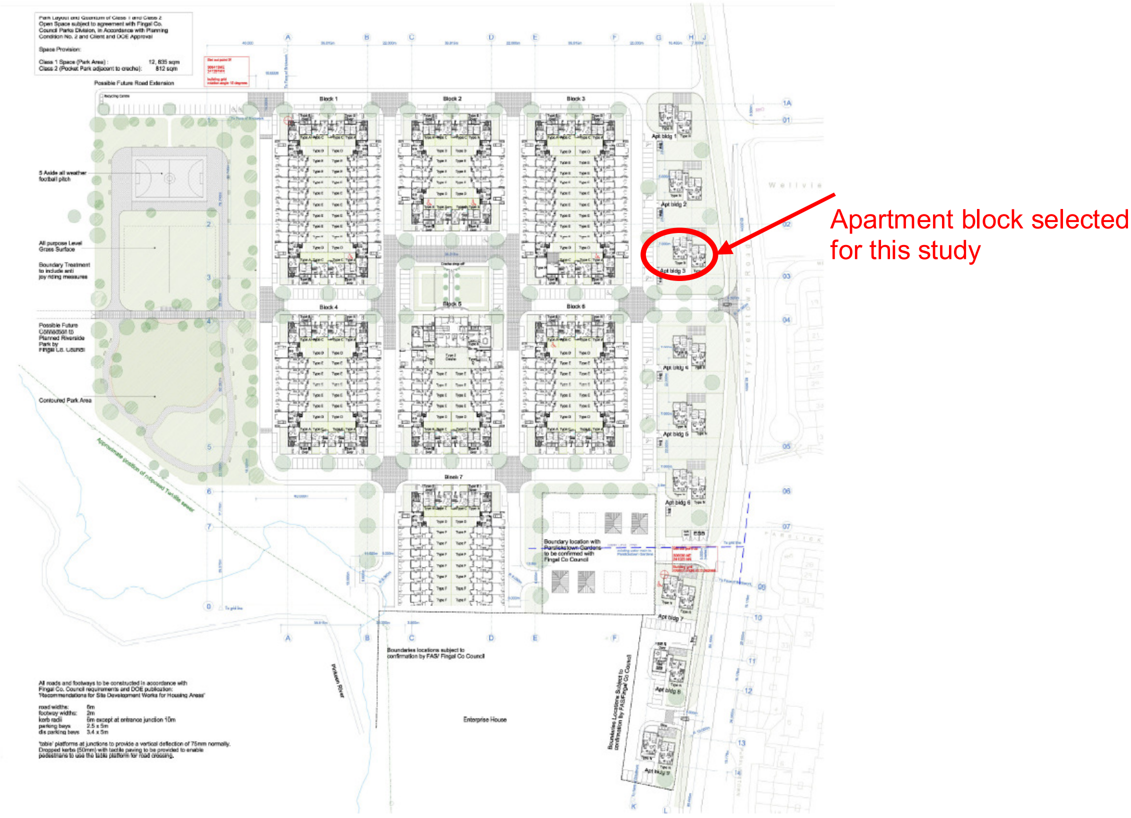

Figure 1: Site plan

Fig 2: 3D model of aparmtments selected for the study.

2. DUBLIN CLIMATE

2.1 Temperature and Solar Radiation.

The Irish climate could be classified as a mild climate, which under classifications as that of Köppen-Geiger would correspond to a maritime temperate climate, without a dry season and with reasonably warm summers [1]. Figure 3 shows monthly mean and extreme daily average temperatures for Dublin airport from 1961-1990.

Figure 4 shows the annual solar radiation in Europe, where we can observe that levels in Ireland would have similar levels to those in other parts of Europe. This fact together with the mild temperatures means that Ireland is in a good position to implement measures that minimize thermal energy use in the domestic sector.

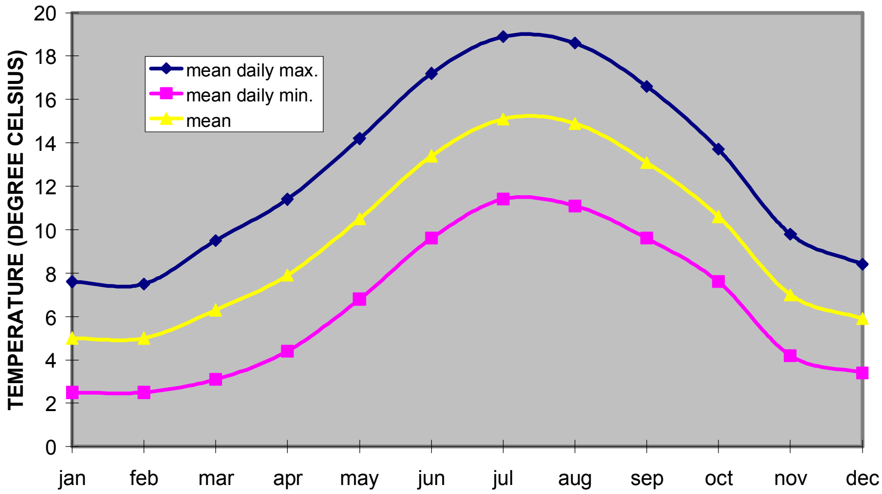

Figure 3. Monthly mean and extreme values [2]

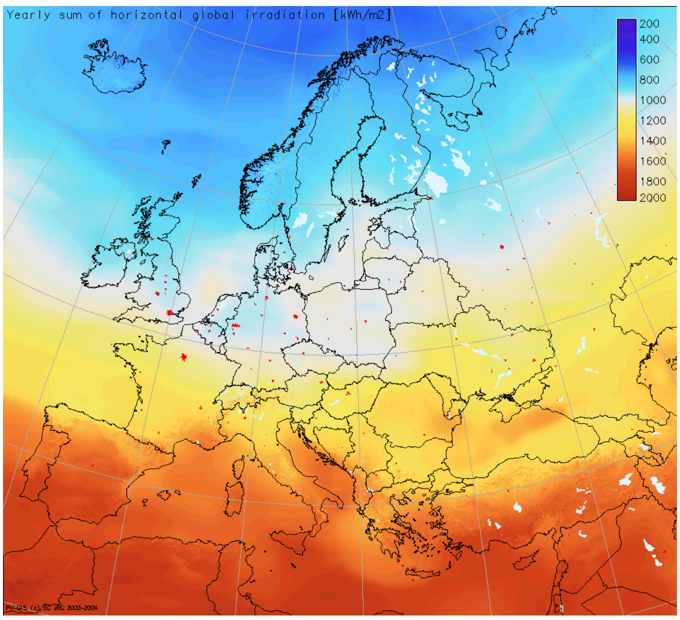

Figure 4. Yearly sum of global irradiation on horizontal surface [kWh.m-2] [3]

2.2 Wind

2.2.1 Winter

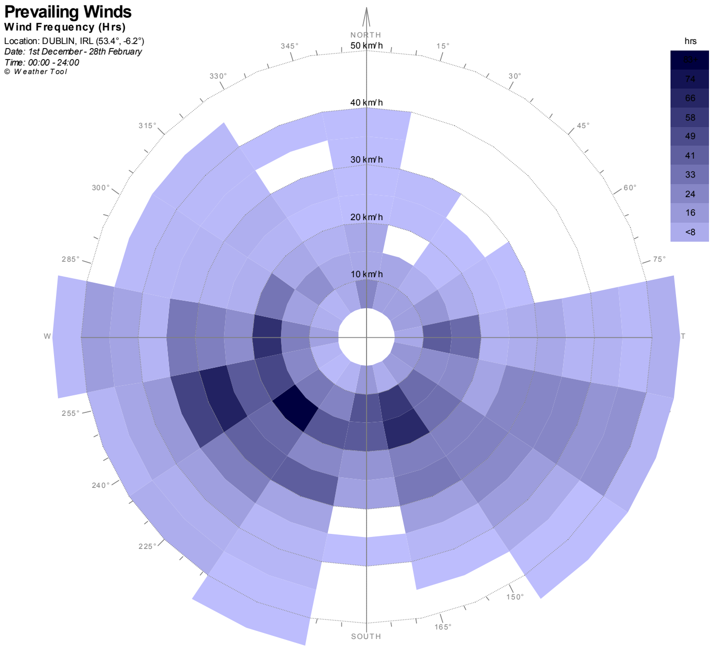

Figure 5. Prevailing winds, wind frequency (hrs), 1st December – 28th February

The wind for the winter period, (1st December to 28th February), comes mainly from West to South-West direction, with the most frequent wind speeds between 20 and 30km/h .

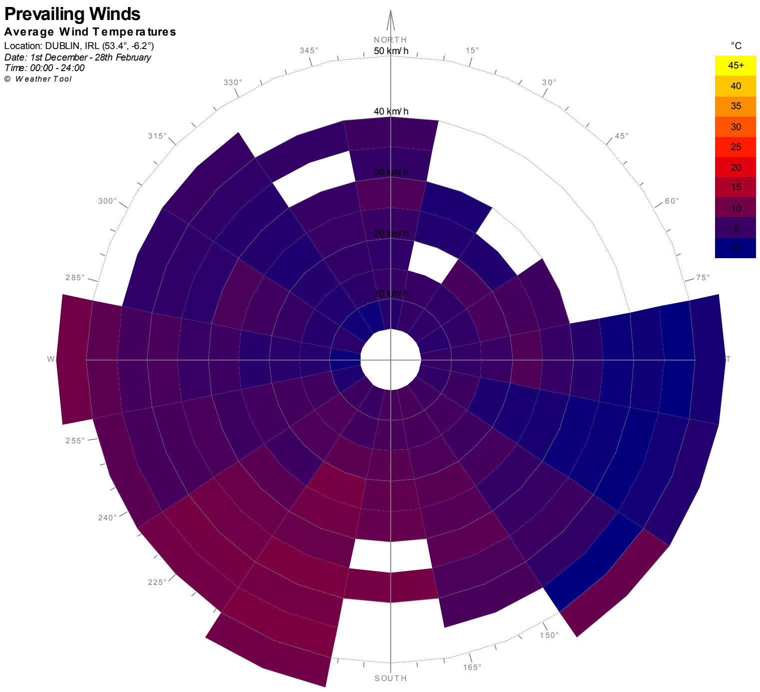

Figure 6. Prevailing winds, average wind temperature (Deg. C), 1st December – 28th February

While the most frequent winds come from the south-west, the coldest winds come from the east in winter, at temperatures between 0 and 5 degree Celsius. The wind sheltering strategies to reduce convection and infiltration should therefore ideally consider both eastern and western directions.

2.2.2 Summer

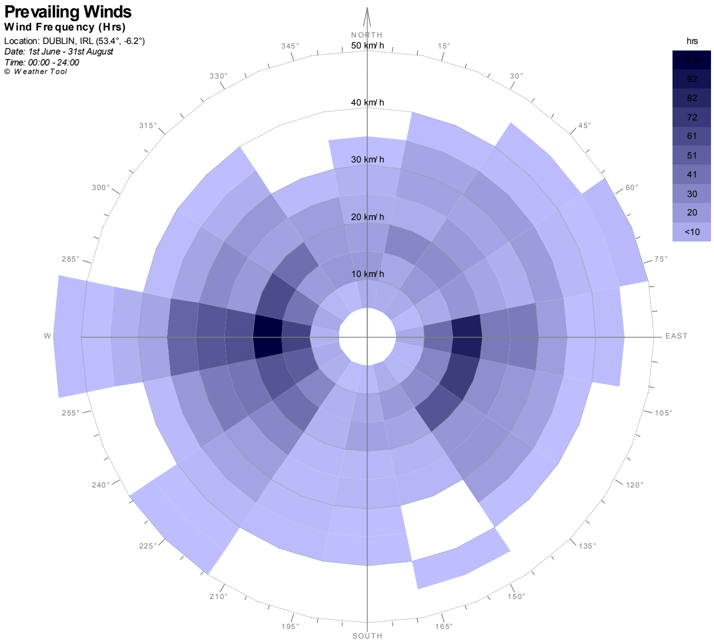

Figure 7. Prevailing winds, wind frequency (hrs), 1st June – 31st August

The wind for the summer period, (1st June -31st August) , comes mainly from West , with variable speeds between 10 and 30 km/h. There is also a high frequency of wind from the east at low speeds (below 20 km/h) from the east.

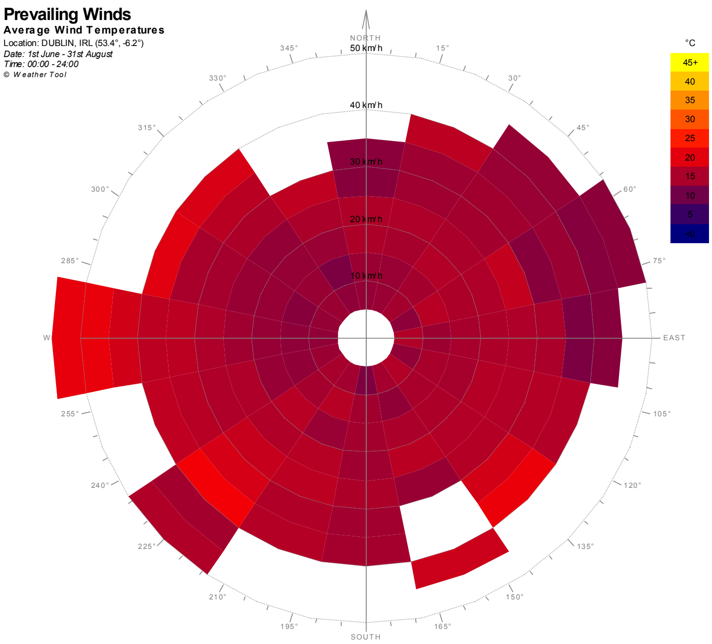

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Figure 8.Prevailing winds, average wind temperature (Deg. C), 1st December – 28th February

The tendency is again that winds with higher temperature come from West to South-West direction, with some high temperature winds also from South-East.

With summer wind temperatures rarely being above 20 degrees, there is an excellent potential for natural ventilation.

3. ENERGY PERFORMANCE SIMULATION

3.1 Modelling Apartment Building

A model of the apartment block 'type N' has been prepared in DESIGNBUILDER software [4]. DESIGNBUILDER software acts as an interface for running the EnergyPlus [5] simulation tool. This tool was chosen for the analysis as it allows for detailed heating, hot water, lighting, equipment, and ventilation calculation with sub-hourly analysis of a number of zones within the house, which is particularly useful for the naturally ventilated house, also allowing a detailed study of the performance of the house during the summer to prevent overheating.

The schedules for simulations, including occupancy, equipment, lighting, activity, etc have been based on data from the UK national calculation methodology [6] and the Irish official method for calculating domestic energy rating [7]. For example , occupancy, lighting and equipment in living rooms and bedrooms for weekdays are defined as follows:

Occupancy:

- Bedrooms: 11pm-08am
- Living Rooms: 08am–11pm

Lighting average energy use during occupancy hours:

- Living room: 3 W/m2
- Bedroom: 1 W/m2

Other equipment average energy use and gains during occupancy hours

- Living room: 5 W/m2 (concentrated at evening times)
- Bedroom: 2 W/m2 (concentrated at late night and early morning hours)

The apartments are naturally ventilated, and a set point of 21 degree Celsius on the living room and 18 degrees on the rest of the rooms has been considered. This temperature is only maintained during occupancy hours.

The weather file used for the calculations is the Dublin IWEC file (International Weather for Energy Calculations) [8]. A view of an apartment floor layout and the model with different zones can be observed in figures 8 and 9.

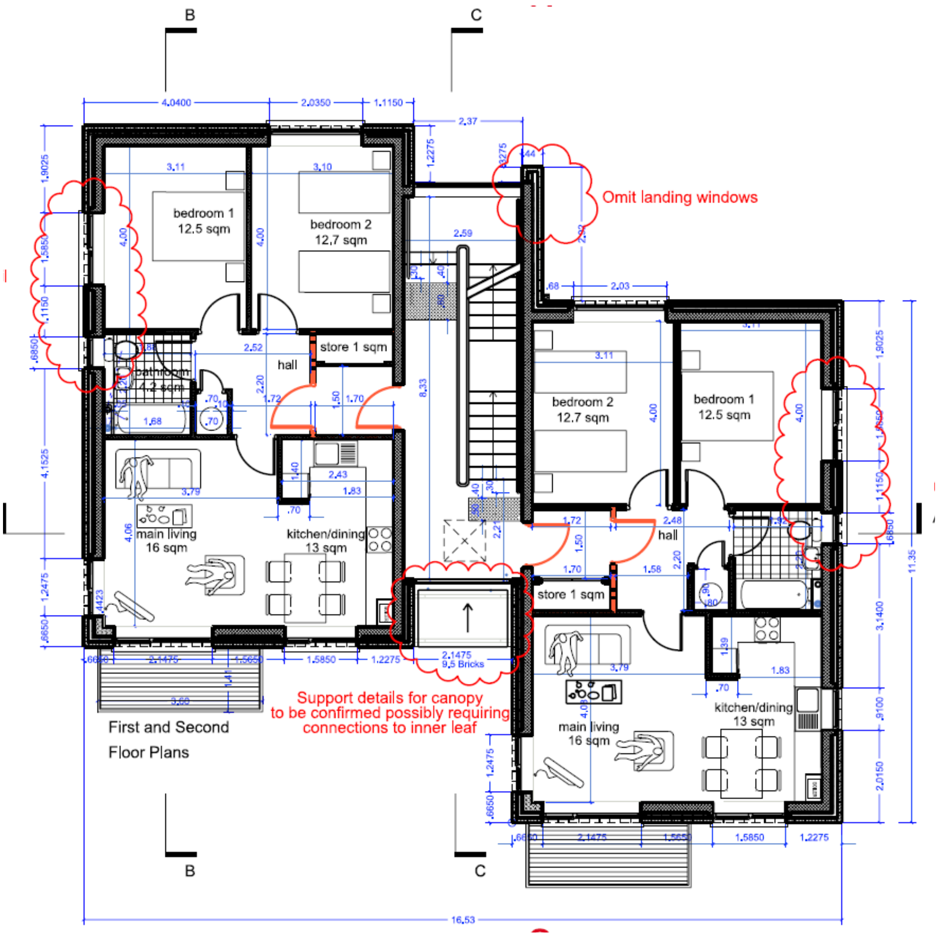

Figure 9. Apartment floor plan

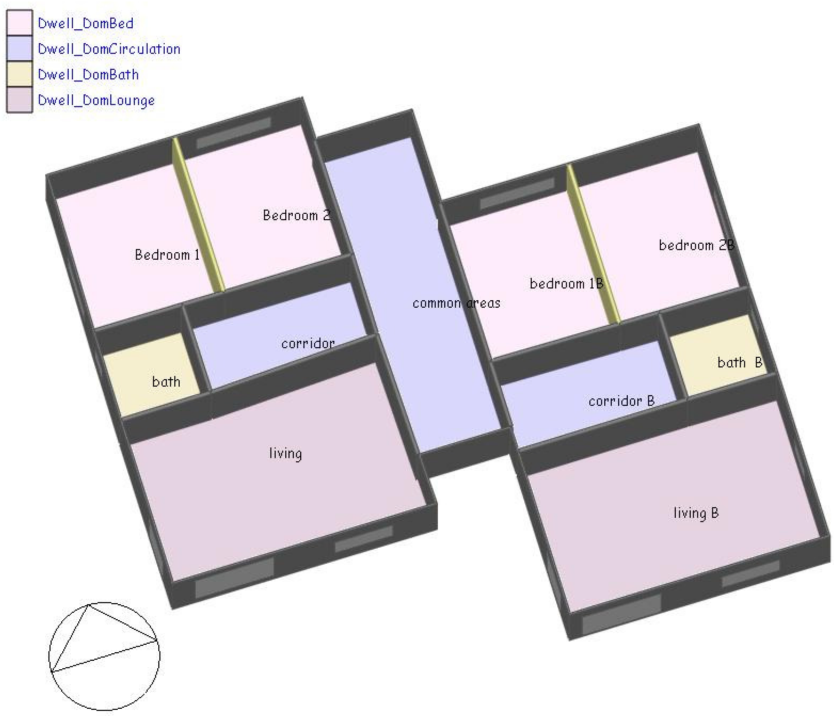

Figure 10. Apartment model showing different zones.

3.2 Building Specifications

Existing - Base Case Apartment:

The existing apartment base case has a typical cavity wall construction conforming with the 2005 building regulations. The maximum U values for the different building elements are defined in the 2005 regulations, and are displayed graphically in Figure 10.

The heating and hot water are provided by a gas boiler with a seasonal efficiency of 78% for the 'base case' study.
Each apartment unit has a total area of 78 square meters,

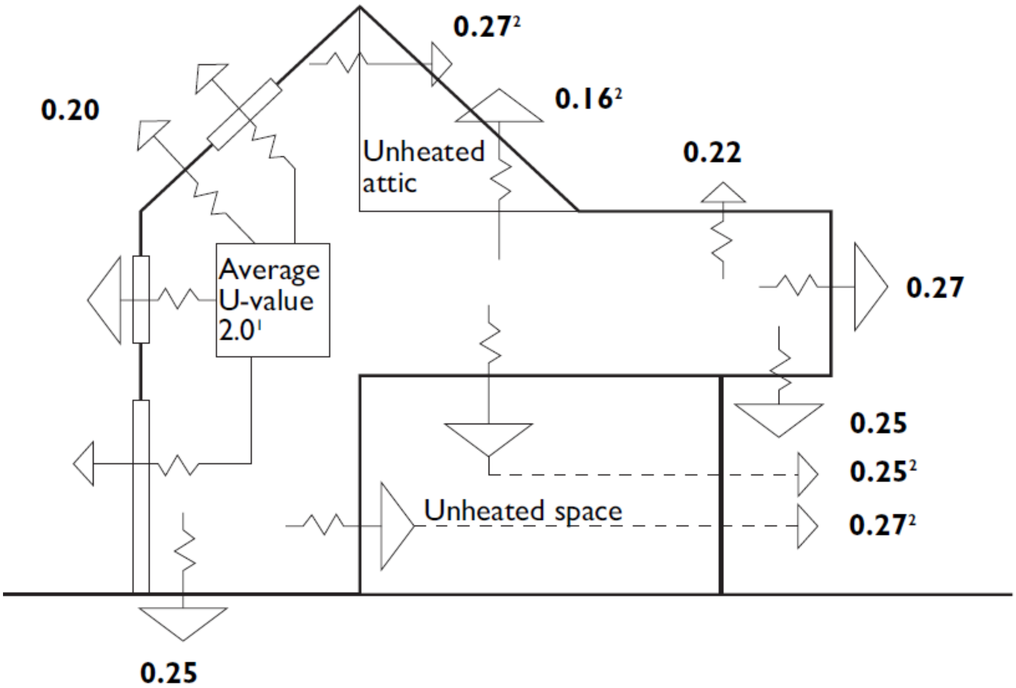

Figure 11 : Average area weighted U values required 2005 (and 2008) regulations. [9]

3.3 Monthly and Annual Energy Uses (Delivered Energy, kWh)

For each of the models in this study , the calculations are run on the EnergyPlus model, just changing the values for the different improvement options.

The outputs of the calculations include detailed hourly analysis of temperatures, heat flows through building elements, heat balances, etc.

Figures 12 and 13 show results for the energy uses on the existing base case.

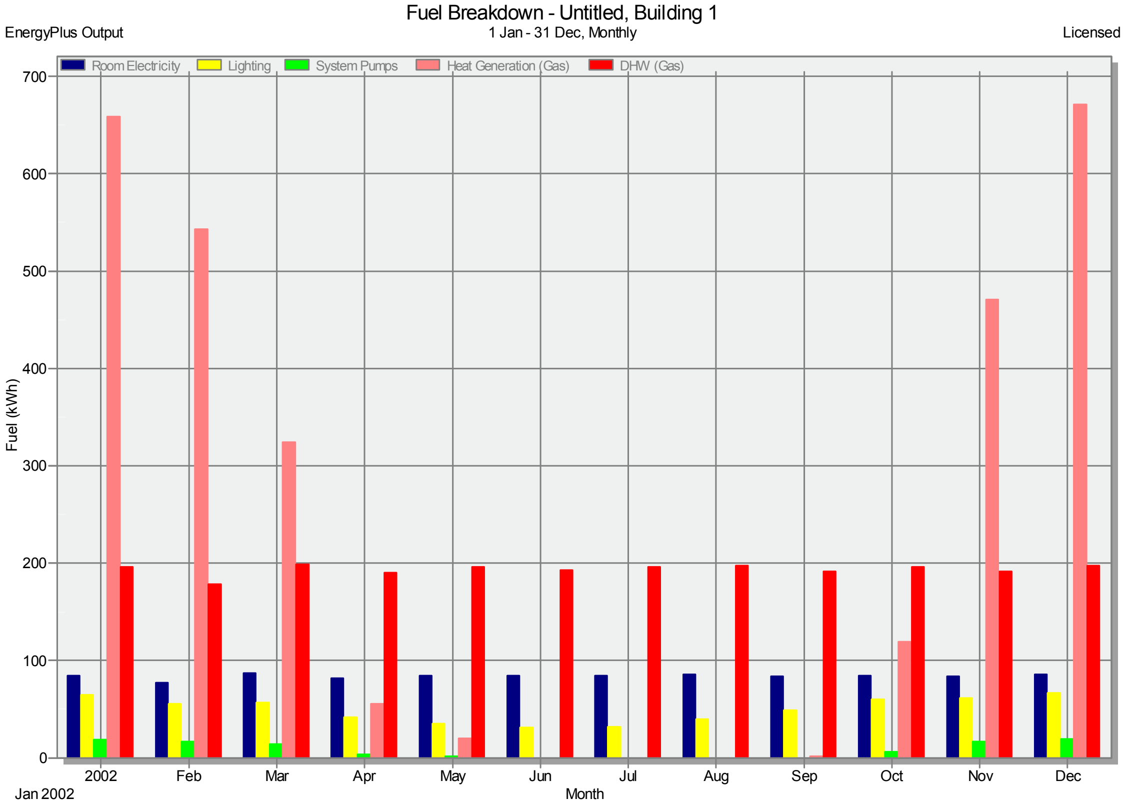

Figure 12. Monthly delivered energy for different energy end-uses.

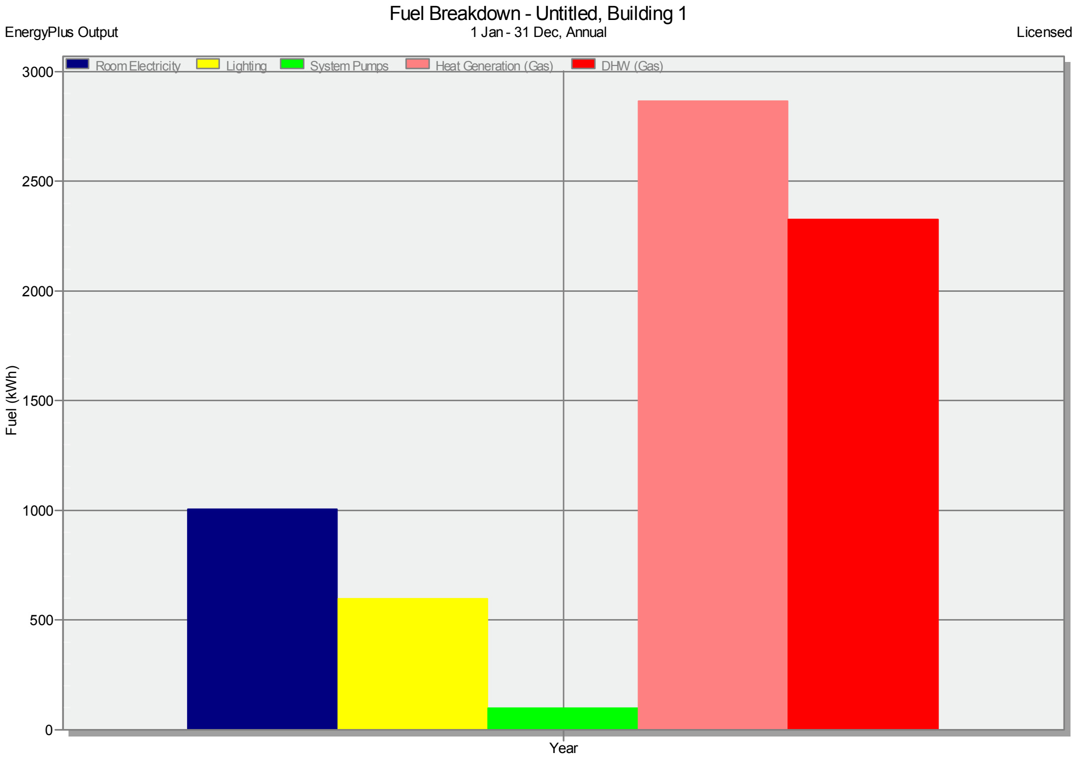

Figure 13. Annual delivered energy for different energy end-uses.

Main energy use is for heating, and occurs mainly between november and march. Water heating is practically constant through the year, and for the defined occupancy equals approximately to 200 kWh per month. The rest of the energy use is delivered electricity , mainly lighting and room equipment and plug in loads. It has to be noted that to present results in terms of primary energy , the values of heating and hot water must be multiplied by a factor 1.1 and the electricity use by a factor of 2.7, as adopted national primary energy conversion factors for Ireland [7].

Total annual energy use for the apartment is then 9,970 kWh.

3.4 Indoor Temperatures.

Indoor temperatures are set to 21 degrees for occupancy hours in the living room, and 18 in the rest of the house.

Figure 14 display temperatures in winter, showing how the temperatures are maintained and reached quickly when the boiler starts.

During the summer, natural ventilation by opening the windows has been scheduled when temperature rises above 25 degrees. It can be noted in figure 15 that with this measure there is not problems of overheating during the summertime.

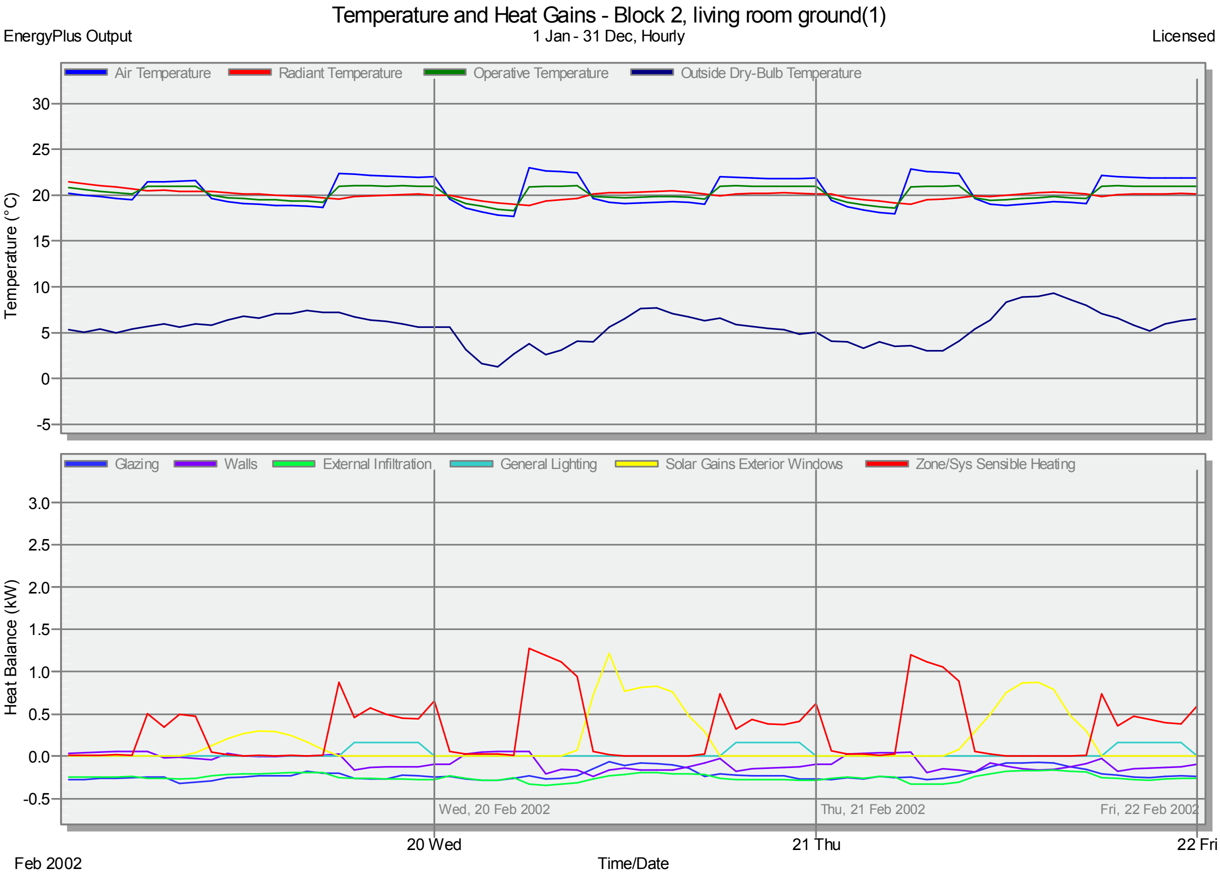

Figure 14 - Living room - Hourly values for typical winter days.

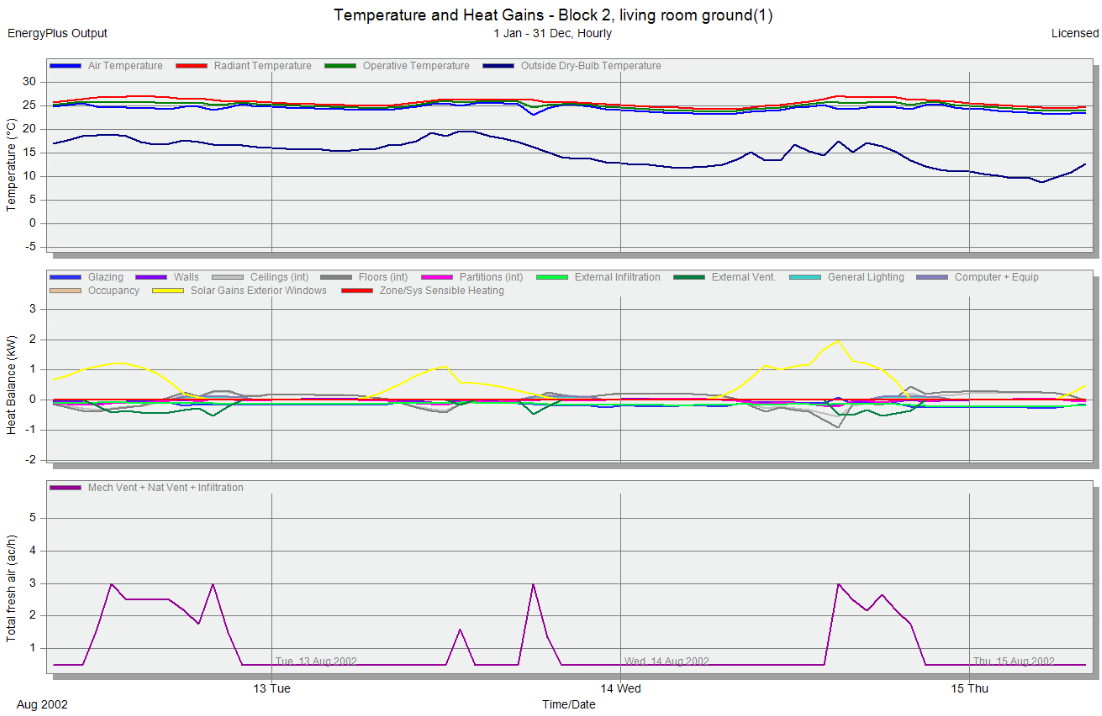

Figure 15 - Living room - Hourly values for typical summer days.

3.5 Conclusions from energy performance simulation

From the hourly analysis of three typical winter days in figure 14 it can be observed that main losses are through external infiltration (air coming through the vents is included as external infiltration), through the windows, and trough the walls. The boiler supplies the necessary heat to keep the room at desired temperature (21 degrees) during occupancy hours with no problem. The overheating during summer does not apparently represent a problem neither if secure natural ventilation is possible.

Based on these observations, it is observed that a reduction of energy use can be achieved by different strategies. In section 4 of this report, the following options will be analyzed through calculation and simulation of energy performance and the use of Net Energy Ratio as an indicator.

- Increasing insulation levels.
- Installing windows with lower U values (triple glazing)
- Installing new boilers
- Adding renewable energies

Other possible solutions that would be commented, although their impact on the building energy performance is difficult to evaluate are:

- Tree sheltering being planted
- Inhabitant behaviour

4. ENERGY PERFORMANCE IMPROVEMENT OPTIONS

This section will use the Net Energy Ratio as an indicator to evaluate different building improvement options. Net Energy serves to compare different energy performance improvement options from a life cycle perspective, which is particularly useful when exploring buildings which are already relatively efficient, and where improvement options mean an addition of materials or systems to the building.
As we intend to move to 'zero energy' buildings and 'zero energy' communities, the net energy ratio is a valuable indicator to assess the impact of building improvement measures from a wide perspective which includes energy uses for the life cycle of each component used, using embodied energy values as a reference.
To establish embodied energy, a key aspect of the analysis is the boundaries of the buildings life cycle. Most common approaches are the 'Cradle to Grave', 'Cradle to Site' or 'Cradle to Gate', the latter including all energy inputs to a product, expressed in *primary energy*, from extraction to manufacturing, until the product leaves the factory gate. This approach is proposed as the basis for this methodology, as it is the most commonly used value referenced in embodied energy studies [10]. The embodied energy is divided by the estimated service life of each element to calculate the annualized embodied energy (AEE), in primary energy units. The annual energy use, also presented in primary energy units, is then divided by the annualized embodied energy to calculate the net energy ratio. The higher the Net Energy Ratio, the better the proposed solution from a life cycle energy perspective. Options with the higher net energy ratio will be a better option to reduce use of earth energy resources.
A detailed explanation of the methodology used can be found in a paper by Hernandez and Kenny [11].

4.1 Increase of the insulation levels:

The embodied energy of this measure highly depends on the materials used. Options as sprayed cellulose would generally have a low embodied energy, while options as polystyrene bead would have a higher embodied energy. There are many other options with different materials in the market, including various types of foams, for which embodied energy and other environmental characteristics are still not very well defined.
For the two materials studied, , the associated approximated embodied for upgrading the external wall surface of an apartment and filling the additional 40mm cavity, based on the Inventory of Carbon and Energy [12] would be :
Polystyrene : 1400 kWh
Cellulose: 200 kWh

If we consider a service life for the insulation of 50 years, which is suggested in many case studies as a typical life cycle of a building before major renovations [10], the annualized embodied energy for each of the options would be very low, 28 kWh/year for polystyrene, and 4 kWh/year for cellulose.

Recalculating the energy performance of the apartment with EnergyPlus with this change on the insulation, we can observe that filling the cavity (which would improve the U value of the wall from 0.27 W/m^2 K to approximately 0.20 W/m^2 K) would save 460 kWh of primary energy per year. The net energy ratio for this measure is therefore very high, of 16 for polystyrene and more than a 100 for cellulose. That means that we would recover over the life cycle of the building more than 16 times the energy employed in the manufacturing of the polystyrene, and more than a 100 times for the case of the cellulose.

4.2 Installing triple glazed windows.

This option assesses the impact of changing existing windows with an U value of 2.2 W/m^2 K with triple glazed, more efficient windows. Embodied energy of windows can be estimated from various studies [13, 14]. We approximate embodied energy of a triple glazed window with a U value of 1.1 W/m^2 K to 400 kWh/m^2. For one apartment, the total embodied energy of changing the windows would be in the order of 6000 kWh. If we estimate the service life of the windows to 30 years, the annualized embodied energy of changing the windows would be 200 kWh/year.

Recalculating the energy performance of the apartment with these windows instead of the existing windows with an U value of 2.2 W/m^2 K, the energy savings would be 650 kWh/year.

The net energy ratio for this measure is therefore quite low, the order of 3.25. If the windows would have been installed at design stage, the net energy ratio of this option would greatlyincrease, as the incremental embodied energy between double and triple glazed windows is small

4.3 Installing a more efficient boiler.

This option assesses the benefits of changing an existing boiler with an efficiency of 78% with a new boiler with an efficiency of 90%.

The embodied energy of a new boiler has been estimated as 1000 kWh from various studies and databases [15-17] For an estimated service life of 25 years, annualized embodied energy is 40 kWh.

Recalculating the energy performance of the apartment with the new boiler, the energy savings are greater than previous cases as hot water production as well as heating benefit from the improved efficiency. The annual energy savings are 750 kWh of primary energy per year, which would correspond to a very high net energy return of nearly 19.

As in the previous case, this net energy return would have been be maximized if this measure had been taken at design stage, as the difference of embodied energy between different boilers is small.

4.4 Adding Solar Domestic Hot Water systems.

The embodied energy values of solar thermal panels and corresponding systems have also been approximated from various references [18-20]. For this study the addition of a $5m^2$ installation is considered, and its embodied energy set to 1600 kWh. The lifetime of the systems has been set to 20 years, which means an annualized embodied energy of 80 kWh / year for the system.

The annual energy savings achieved from this system are 1200 kWh per year, so the net energy ratio for this option is 12.5 .

4.5 Adding a Photovoltaic System.

There is a wide variation in the range of embodied energy values published for PV panels and installations. The values used here are approximated from various references as [21-24]. The embodied energy of a PV installation is set for this paper to 1700 kWh per m^2 of installation. A lifetime of 25 years has been considered. Annualized embodied energy for each square meter of PV equals to 68kWh of primary energy. Annual production of a properly installed PV system in Ireland could yield 120 kWh of electricity which would equal to 324 kWh of primary energy. The net energy ratio for a photovoltaic installation would be 4.8.

4.6 Planting trees as a shelterbelt.

Planting trees as a shelterbelt could be an option to consider for the western side of the site, which could reduce at least the coldest winds of the year, if not the most frequent ones.

Quantifying the effect of sheltering with trees is very difficult. Trees would have the positive effect to reducing air speed around the building and thus the convection coefficient of the envelope, and also the air infiltration and unwanted ventilation on the apartments. A close dense shelterbelt has also the property of reducing the radiative losses of the building, as the trees would reduce long wave radiation particularly at night when sky temperature is very low.

Combined dynamic simulation with computational fluid dynamics can be used to assess the influence of those factors on the energy performance of the building [25, 26]. Without performing such detailed calculations, it has to be noted that this measure, as it requires practically no additional embodied energy for its implementation (some authors would argue that embodied energy of this measure would be negative), would have a very high net energy ratio no matter the small the energy benefits.

4.7 Occupant behaviour

Energy use between identical dwellings on the same site, often has completely different patterns between different users. The first and most efficient measure to reduce energy use in a building is to have an energy conscious inhabitant. The net energy ratio of any measure taking by the occupant that improves the energy performance of the building without any physical changes to it would be of infinite. Therefore is obvious that building energy manuals, smart metering, energy coaches and any other educational activities that promote and encourage energy savings would be optimal from a life cycle perspective, particularly in the current times where house plug-in and residual loads tend to increase.

	INCREMENTAL EMBODIED ENERGY	SERVICE LIFE	ANNUALIZED EMBODIED ENERGY (AEE)	ANNUAL ENERGY SAVINGS (AES)	NER ENERGY RATIO (AES/AEE)
ADDITIONAL INSULATION - POLYSTYRENE	1400	50	28	460	16.4
ADDITIONAL INSULATION - CELLULOSE	200	50	4	460	115.0
TRIPLE GLAZED WINDOWS	6000	30	200	650	3.3
NEW BOILER (90 % EFFICIENT)	1000	25	40	750	18.8
SOLAR WATER HEATING (5 M2)	1600	20	80	1200	15.0
PHOTOVOLTAICS (PER M2)	1700	25	68	324	4.8
TREE SHELTER	-	-	-	-	VERY HIGH
OCCUPANT BEHAVIOUR	-	-	-	-	INFINITE

Table 1. Summary of Results for the different improvement options.

5. DISCUSSION AND CONCLUSIONS.

It is a big challenge to find viable solutions for retrofitting the portion of the housing stock built over the past 10 to 15 years, which typically offers fewer options for cost-effective improvement than older buildings, while still having a medium to low energy performance which is far from the desired path to zero energy buildings.

This report employs an innovative method for assessment of Improvement options, which is based on the concept of Net Energy Ratio. In theory, an option with a Net Energy Ration above one (energy savings greater than energy employed implementing the option) should be beneficial for a community or society. In practice, perhaps linked to the fact that the boundaries for calculation of embodied energy values for construction goods are limited, we need high Net Energy Ratios for options to be likely to be applied, and we should look for the options with the highest Net Energy Ratio as a priority.

With this is mind, and as it can be observed in the summary results (Table 1) , that possible best options would be those that require no natural resources, and could include tree shelter planting and measures to promote energy-conscious occupant behaviour that helps to improve energy performance.

From the physical measures, we can observe that insulating with renewable or recycled materials as cellulose has a very high Net Energy Ratio, as the process does not involve a large amount of natural resources, while reducing heating energy use. Insulating with energy –intensive material, although not as effective, is still a very good option from a life cycle energy perspective, with a net energy ration over 16.

Changing windows from an efficient double glazing to triple glazing has a net energy ratio of just over 3, a low value that means that is not the best option , being even below the installation of photovolotaics, which has a net energy ratio of nearly 5.

Upgrading the existing boiler to one more efficient or installing a solar water heating systems have high net energy ratios of 18 and 15 , which mean that both are in practice good solution from a life cycle energy perspective.

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