Department of Mechanical and Aerospace Engineering

Evaluate the Feasibility of Passive House in China Context

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Copyright Declaration

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Abstract

In May 1988, the concept of Passive House was created in Germany with a lot of research projects. And in 1990, the first Passive House residences were built in Darmstadt, Germany. Until today, there are more than 25000 certified Passive Houses in the whole world, involves the first Passive House in Dunoon in Scotland which is used as a model in this project. Additionally, in the Expo 2010 in Shanghai, German built a certified Passive House which is the first one in China.

So this project will evaluate the feasibility of Passive House in China context. As the background of energy in China is so serious, about one third of the energy consumption amount is imported from other countries, and the energy efficiency is lower around 35% than in Japan and USA, and also the huge energy consumption because of the fast growth of population. The environment pollution is also another problem in China. However, the emergence of Passive House will reduce and save more energy consumption, with just not more than 15 kWh/m^2 in heating demand, a peak load of 10 W/m^2, and with not more than 120 kWh/m^2 in total primary energy consumption.

The project focus on the Passive House in Dunoon, and with improving its windows, ventilation, shading to make sure it will have a good performance in China context. The main method is through PHPP (Passive House Planning Package) to analyze the performance of Passive House. Then input the climate data in three different climate zones in China to find out its different performance. And the results show that it has a big problem about the overheating. Finally, with the study of the climate condition, more technical problems and legislation in China, evaluate the feasibility, and the final research findings have showed that the Passive House is feasibility but not now.

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1. Introduction

After 1950's, because of the oil crisis which has the immense effects to the world economy, the world opinion began to turn their attention to the problem of the world energy crisis. There were even many predictions: world oil resources will dry up, and the energy crisis will be inevitable. If people don't make a big effort to use and develop all other kind of energy resources, then the humanity in the near future will face the serious problems of energy shortages. As is known to all, energy is the national economic lifeblood, but the energy sources are limited. So in order to fight for control of resources and energy, there were two world wars outbreak, and many other small wars. During 1973-1974, the first oil crisis came from the fourth war in the Middle East. From 1979 to 1980, the second oil crisis caused by the Iran-Iraq war, which struck the western countries again [1]. However, Japan studied the experience from the first oil crisis, and carried through a large scale industrial adjustment, increased utilizing energy saving equipment, promoted nuclear power generating capacity. As a result, GDP in Japan kept the average growth rate of 33.5% in the second oil crisis. The Gulf war in 1990 is just for oil. Therefore, it's important and urgent to have a new industrial revolution through rapid development of renewable energy and comprehensive replacing biochemical resources. This is not only the reason for survival, but also for the sustainable development for the whole world.

Since 1990, renewable energy has developed rapidly in Germany because of the adopted energy policies by the German government and the European Union. And the legislation such as the 1990 Electricity Feed Law and 2000 Renewable Energy Law have played important roles in advancing the development of renewable energy technologies [2]. For example, the installed wind capacity has grown by more than 2000% since 1990, solar photovoltaic by more than 15,000% and biomass by more than 500% [2]. Additionally, the renewable power producer will be offered large subsidies and government loans because of the laws. By 2010 the renewable share of the electricity generating fuel mix to 22% as the reason of a 1997 Directive on Renewable Energy Sources adopted by the EU. In the same way, the Kyoto Protocol which was ratified by EU also encouraged all the EU members to reduce their greenhouse gas by using of renewable energy. At the moment, renewable energy technologies have been a long-term German energy strategy to reduce greenhouse gas emissions and other environmental problems. And the reduction of oil and gas imports now has satisfied 62% of German energy demand, the high technology exports also contributes to German economic growth.

Facing to climate change, apparently to curb greenhouse gas emissions is more and more urgent, and the key point is the total greenhouse gas emissions. However, through increases in energy efficiency, the energy used in buildings can be reduced. In this area, the Passive House Standard which is developed by the Passive House Institute has an excellent solution for efficient energy use in buildings. Passive House stands for green, healthy and comfortable living with the impressive energy efficiency, also regardless of the regional climate. In the last several years, thousands of Passive House buildings have been built. Most are located in Germany and Austria. And also more than 200 such buildings appeared in UK including the first Passive House in Dunoon, and the details will be talked about in this thesis. In order to advance the Passive House Standard and the quality which it stands worldwide, the Passive House Institute founded the International Passive House Association (iPHA) [3]. It includes architects, planners, scientists, suppliers, manufacturers, contractors and property developers, and it works to promote the Passive House Standard and foster a greater public understanding of its significance.

In China, as a populous nation and a major energy consumer, energy demand is great, but the energy source is insufficient in domestic, especially in recent years, the same serious environmental problems emerged in China. So it is urgent to conserve energy and develop renewable energy technologies. But Passive House showed a bright way for China to solve such problems and reduce the risk of energy crisis although it’s a new concept in China. Especially the first certified Passive House was built by German in the Expo 2010 in Shanghai, which showed that it is possible to develop Passive House in China to save energy. So in this thesis it will talk about the feasibility of Passive House in China context.

1.1 Aims

The aim of this project is to evaluate the feasibility of Passive House in China context. And as there are many different climate zones, it is important to evaluate the feasibility in different zones, and find out the appropriate place to build Passive House.

1.2 Objectives

The first objective is through PHPP (Passive House Planning Package) to find out the performance of Passive House in Dunoon, and improve it to make sure it will have a good performance as a model in China context. The second objective is through changing the climate data (use Chinese climate data), and some details to find out the performance of Passive House in different climate zones in China, and then focus on the climate condition, technology, material, economy and legislation of China, evaluate the feasibility in China.

2. Literature Review

As the Passive House is a new concept, especially in China, it's important and necessary to be familiar with the basic knowledge of the Passive House. And to assist in approaching the project, the following topics will be discussed which is relevant with this project and is interested in:

- **The Concept of Passive House**
- **PHPP**
- **Passive House in Different Climates**
- **Passive House Projects**
- **The First Passive House in China**
- **Summary**

2.1 The Concept of Passive House

The standard of Passive House is leading the world in energy efficient design. At first, Passive House was designed for residential buildings in Central Europe. Until today, it can be implemented in all types of buildings, such as office, school, etc, and is almost suitable in any place in the world. However, before the standard of Passive House appeared, there have been some such "superinsulated buildings" in some place. For example, in Southern China where cooling is needed, but there are some traditional buildings with unique construction, heating and active cooling is not required. And these buildings were thought as Passive Houses by Bo Adamson [4], which also gave them the ideas to study Passive House.

Figure 1: Traditional Passive Houses in Southern China (source: passipedia)

The Research Ship "Fram" was known as the first fully functioning Passive House, but it was a polar ship not a house. Fridtjof Nansen [5] described that the total thickness of saloon and cabins was just about 15 inches, it was a comfortable abode with the temperature around 22 ℃ and fire was not required in the stove, as the air sail was rigged up, the ventilation was excellent, it was warm and comfortable to sit in there with only a lamp burning.

Figure 2: Fridtjof Nansen's polar ship (source: passipedia)

There are many such Passive Houses in the early time, but also have many significant problems. The airtightness is not permanent, the performance of windows is not satisfying because the windows were small and covered with temporary insulation.

In May 1988, the standard of Passive House was established by Professors Bo Adamson and Wolfgang Feist. In 1990, the first Passive House was built in Darmstadt, Germany, and occupied by the clients in the following year [6].

Figure 3: Southern view of the Passive House in Darmstadt-Kranichstein (source: passipedia)

So what is a Passive House? It is a building with efficient energy, comfortable, affordable and ecological living environment at the same time. It is not just a low-energy building or a superinsulated building. The energy saving of Passive House is up to 90% compared with the typical buildings in central Europe, and over 75% compared with some new constructions [7]. Besides, Passive House uses less than 1.5 litres heating oil per square meter of living space per year which is far less than the low-energy buildings. The energy saving also is proved in warm climates where buildings require more energy for cooling than for heating.

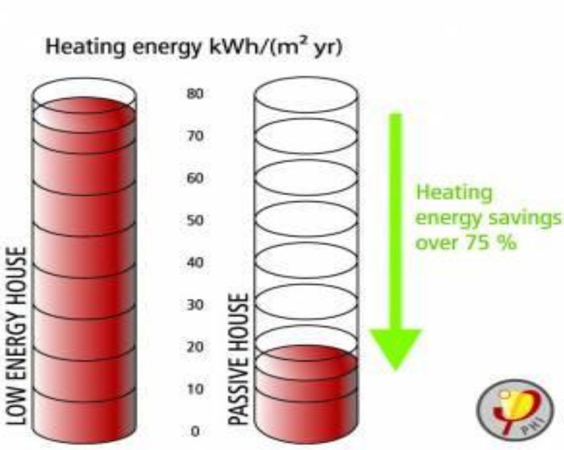

Figure 4: Heating energy comparison (source: passipedia)

Additionally, Passive House has high level of comfort because of the energy source is inside the building, such as body heat from residents and solar heat. The unique design of windows and building shell with highly insulated walls, roof and floor slab keep the building warm, and reduce heat loss. The “sensible” ventilation system is another key point which supplies fresh air and also re-uses the heat contained in the exhaust air with a highly efficient heat recovery unite. The energy saving of Passive House is a great deal which can be seen below shows the consumption values measured in low-energy houses and in Passive House. The Passive Houses Standard is a sustainable construction standard, and the Resolution of the European Parliament of 31 January 2008 [8] calls for its implementation by all member states by 2011. On 17 November 2009 the European Parliament and the Council fixed 2020 as a deadline [9] for all new buildings to be nearly zero energy buildings.

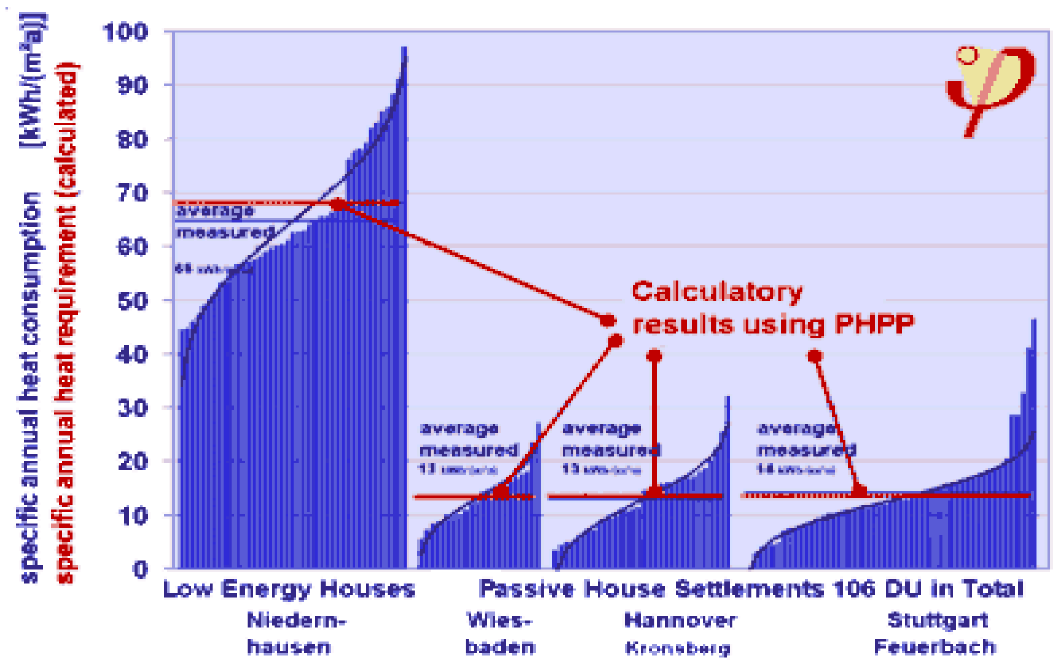

Figure 5: Heat consumption measured in 4 residential estates: one low-energy estate (left) and three Passive House estates (source: passipedia)

The concept of Passive House doesn’t only work on paper, it has been proven to work in real life. There have been more than 20000 Passive House dwellings built and monitored in the world with respect to air quality, thermal comfort, energy consumption and so on. All of the results have showed that the criterion, standard and concept reached the expected performance. It has the high level of comfort during cold and warm months which is also confirmed by Passive House residents. It has the high level of insulation and airtight because of thermal bridge free design. It is eco-friendly with extremely little primary energy utilization and sufficient energy resources without causing any environmental damage. It is affordable to begin with and also save money in the long term which makes it feasibility in many countries. It is versatile with the Passive House standard can be used for administrative buildings, schools and so on. The Passive House standard also can be achieved in retrofits using Passive House components. The most important is it is Passive House – sustainable.

The exact definition of Passive House is as follows: *A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air [10].* It's just a functional definition without any numerical values and is valid for any climates. The definition also shows that the Passive House is a fundamental concept not a random standard, it was discovered not invented by anyone. There are five performance criteria for Passive House standard [11].

- The special shape and orientation of a building to reduce heat loss and maximise solar gains.
- High level of insulating of the building fabric with thermal bridge-free construction and low wall, roof and floor U-values about 0.15 W/(m ?K), about 300mm of insulation,
- With airtight fabric reducing ventilation heat loss below 0.6 ach-1 @ 50Pa (6-10 times better than standard UK construction).
- With mechanical ventilation system and heat recovery providing fresh air without additional heat loss.
- The primary energy demand is reduced to less than 120 kWh/m^2 per year, and greenhouse gas is also reduced with renewable energy systems.

The criteria also can be seen as the table below:

Heating energy demand	≤15 kWh/(m^2a)
Or Building heating load	≤10W/m^2
Useful cooling demand	≤15 kWh/(m^2a)
Primary energy demand	≤120 kWh/(m^2a)
Building airtightness	≤0.6/h
Excess temperature frequency	≤10%
Airtightness	n_{50}≤0.6/h
Heat protection (thermal bridge free)	U≤0.15 W/(m^2K), U_w≤0.8 W/(m^2K)
Triple-glazing	U_g≤0.8 W/(m^2K), g-value 50-55%
Electricity demand	Max 0.45 Wh/m^3
Ventilation with ≥ 75% heat recovery	

Table 1: Passive House criteria

On the other hand, the Passive House has such fantastic performance because of its special characteristic.

- Superinsulation

With a wide range of thermal insulation materials, the superinsulation of the Passive House is significant to reduce the heat transfer through walls, roof and floor, although it will affect its façade. It can be seen as below, the yellow part is thermal insulating layer, and left side is the thickness of typical insulting layer, right side is for Passive House.

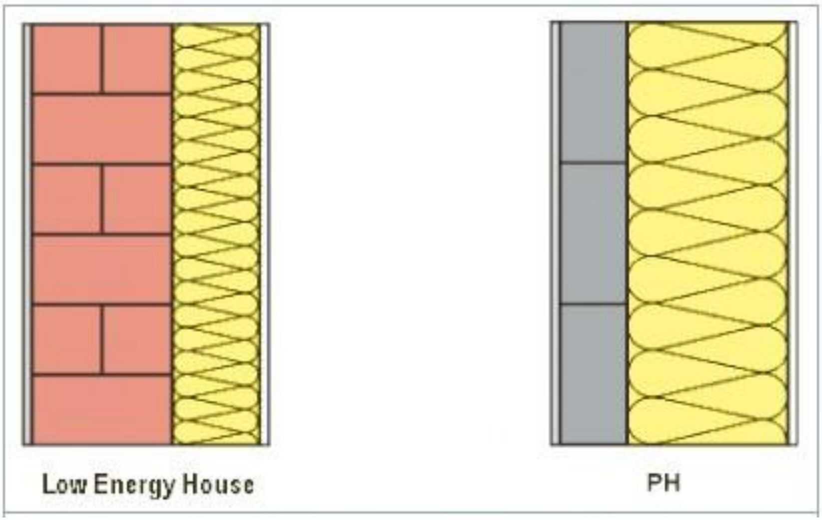

Figure 6: Super thermal insulation (source: passipedia)

- Advanced window technology

The requirement of the windows is much higher for Passive House. The windows are manufactured with high R-values combine triple-pane insulated glazing, low-emissivity coatings, sealed argon filled inter-pane voids and so on [12]. To reach the criteria, the heat gains from the sun are greater than the heat loss, even in winter.

- Thermal bridge free

The design of thermal bridge free can avoid condensation and mouldiness on the interior wall in the Passive House.

- Airtightness

Passive House is required to be extremely airtight, or if the seal is bad, it will result in the convection and finally lead to heat loss.

- Ventilation system

The natural ventilation is an indivisible part of Passive House, but when the ambient climate is not conducive, the mechanical heat recovery ventilation system should be used to maintain air quality in Passive House, with a heat recovery rate of over 80% and high efficiency electronically commutated motors [12].

2.2 PHPP

In this project, the Passive House Planning Package (PHPP) is the main tool to analyze the performance of Passive House, it is an important tool for designing Passive House with a spreadsheet workbook and a manual. It's far more than just an energy calculation tool. By using the PHPP, a functioning Passive House can be designed and also can be confirmed if it can reach the Passive House criteria because it includes all of the tools which are needed, such as the energy balance calculation, design of windows, comfort ventilation system, heating and cooling load, calculation of auxiliary electricity, primary energy requirements, climate data sheet, etc.

Figure 7: Passive House Planning Package – PHPP (source: passipedia)

PHPP is more accurate for energy efficient buildings than other tools, it was developed by adjusting the utilization rate function with the results of dynamic simulation models [13]. And the results from PHPP also have been compared with the monitoring results of large samples of built Passive House. Meanwhile, the boundary conditions used in PHPP are different from the calculation process used for the German Energy Conservation Ordinance (EnEV).

2.3 Passive House in Different Climates

There have been a lot of Passive Houses built in Central Europe, and other countries also want to build Passive House because of its great performance. However, the building tradition in every country is specific, the climate conditions in every region are specific, so there should be the specific solutions for a Passive House to be adapted to the country and the climate. For the case of heating load, the heating load should be less than $10W/m^2$ to reach the Passive House criteria. In some climates it may be easy to achieve, but in some colder climates it may be more difficult. But the final goal of the solutions is the same in different countries. Finally, the Passive House should have a high level comfort of indoor climate, and then all persons would like to live in. The solution should be affordable, or it will not be attractive in a competition with conventional technology. Insulation should be applied in all climates. Shading is also needed especially in the climates with high solar radiation in summer time. Heat recovery is necessary, with a ventilation system, the supply air duct can be well used to transport heat during cold season, cool air in the hot periods and dry air to dehumidify.

As this project is to evaluate the feasibility of Passive House in China context, there will be some challenges because there are many different climate zones in China. And three climate zones will be chosen: Beijing in the north with cold climate, Shanghai in the middle with warm climate, and Hong Kong in the south with hot climate. There should be different solutions to reach the criteria of Passive House, and feasibility in the three climate zones may be different because of different performance. The details will be talked about in the later chapter.

2.4 Passive House Projects

Until today, there are more than 25000 certified Passive Houses in the whole world. The map of the certified Passive House buildings on record with the Passive House Institute can be seen below.

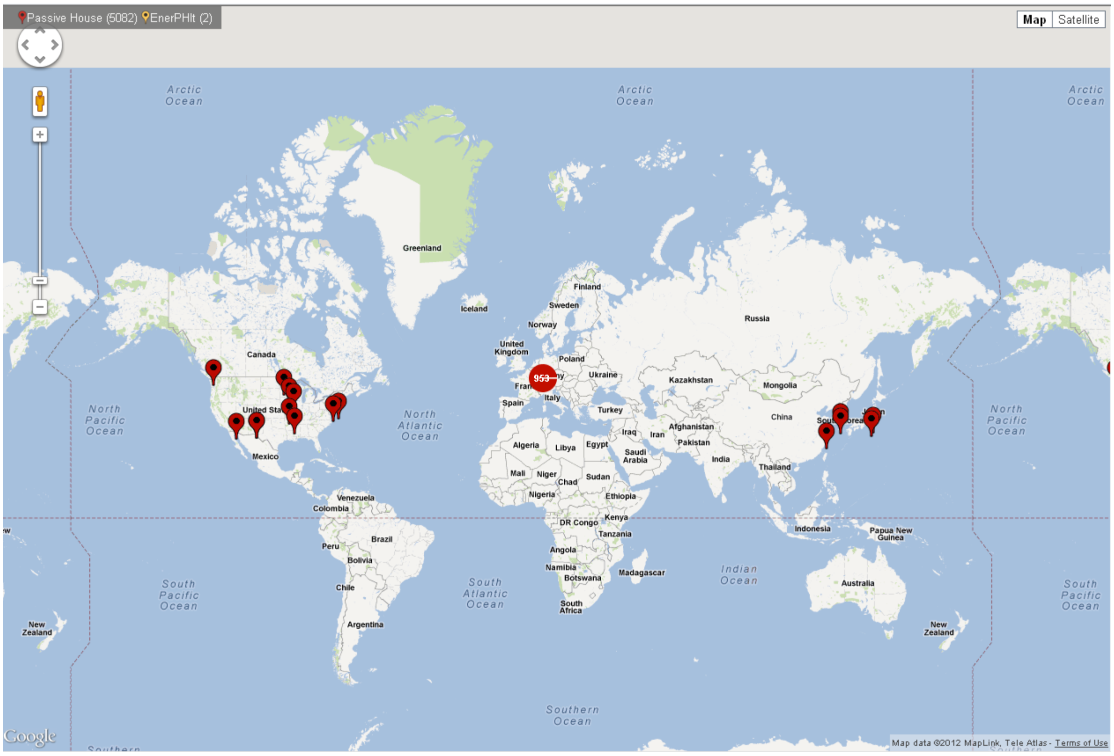

Figure 8: Map of Certified Passive House Buildings (source: iPHA)

Similarly, there have been various Passive House buildings in the UK. The Scottish Passive House Centre (SPHC) is at the forefront in the UK for Passive House consultancy and certification. It is involved in a lot of projects of Passive House in the UK.

- **Crossway – the Grand Design Eco Arch**

Crossway is a very exciting Passive House project incorporating new technologies, and it achieved Passive House certification on the 12th July 2010 [14]. The house located in the countryside with zero carbon passive design, it has habitat for native flora and fauna. There are 4 bedrooms, and the house is built using local materials and a few recycled materials, such as newspapers, car tyres and crushed bottles are used in the lime mortar and in the polished ground floor. It is a light and healthy family home. Its arch shape minimizes the mass, so it looks like a camera lens. The arch is only 120mm with spanning 20m and 8.5m high, it can still support 300mm site spoil seeded with meadow plants from nearby Marden nature reserve [14]. The porous clay is used and it can naturally control humidity, the heat recovery ventilation, triple glazing and high level of insulation can reduce the energy used in the house. The electricity and store thermal energy is generated by the pioneering energy system. The on-site waste treatment and rainwater harvesting are also installed in the building. The PCM thermal stores works well to provide 100% free hot water and generate almost about 700kWh electricity, and biomass wood pellet back-up but is has not been used yet. The MVHR, airtightness are excellent, the indoor temperature never below 16 ℃, the relative humidity regulates at 51%, and no dust mites, etc.

Figure 9: Richard Hawkes' Grand Designs Passivhaus (source; SPHC)

- **Underhill – England's first certified Project**

On 29th January 2010, the Underhill House got the Passive House Certification, and therefore became the first certified Passive House in England [15]. The location of this house is at the top of a hill in the Cotswolds Area with the outstanding natural view. It is glazed to the south, and the highly insulated creates the perfect passive solar design. The structure is entirely concrete. It has large solar collector area in combination with a 2000 litre accumulator tank provides DHW.

Figure 10: Underhill Passivhaus Project (source: SPHC)

Tygh-Na-Cladach is the first certified Passive House in Scotland which located in Dunoon, and in this project, this house will be improved to adapt the climate condition in China. The details of Dunoon Passive House will be discussed in the next chapter.

2.5 The First Passive House in China

In the Shanghai Expo in 2010, the city of Hamburg has introduced a new building concept – Passive House [16]. It is also the first certified Passive House in China. Especially in Shanghai with the extremely high temperature in summer, air conditioning is essential, so it consumes a large amount of the city's energy. But the Passive House can keep the room cool in summer and warm in winter without the air conditioner. And this house has a huge future in China because it doesn't need very expensive and complex high-tech applications. Just with lots of simple technologies, the house can also achieve high energy saving aims in China.

Figure 11: The Ultra-low Energy Hamburg House at Shanghai EXPO 2010 (source: BASF)

As a result, this project is aimed at evaluating the feasibility of Passive House in China context, and will looking for different performance of Passive House in different climate zones in China. The details will be discussed in the later chapter.

2.6 Summary

After finishing the literature review, it can be seen that the Passive House should be suitable in any kind of climate conditions, just by changing its construction, windows, shading, etc, to reach the criteria, and it's also affordable. Thus, the following works will be continued to evaluate the feasibility of Passive House in China context.

2.6.1 Research Questions

The project will focus on the Passive House in Dunoon, and improve it. Then use the modified Dunoon Passive House as the model to put it in China context. Focus on the climate condition, technology, material, economy and legislation in China, evaluate the feasibility in China.

2.6.2 Research Methods

First of all, the main method is through PHPP (Passive House Planning Package) to find out the performance of Passive House in Dunoon, and then improve it to reach the criteria. The next step is to input the climate data in three climate zones in China, find out the performance. If the final results can't reach the standard of Passive House, change some details to improve it. Finally, focus on the climate condition, technology, material, economy and legislation in China, evaluate the feasibility in China.

3. Case study of Dunoon Passive House

The first step of this project is to learn more about the Passive House in Dunoon, because it will be the model in China context. The following topics will be talked about in this chapter:

- **Introduction of Dunoon Passive House**
- **Climate in Dunoon**
- **Technical Details of Dunoon Passive House**
- **Challenges of Dunoon Passive House**
- **Feedback from Home Owner**

3.1 Introduction of Dunoon Passive House

Along the river Clyde, the first certified Passive House in Scotland, and also the first affordable Passive House in UK is being built in Dunoon for Fyne Initiatives: In a row of 10 semi-detached houses [17]. The houses are known as Tygh-Na-Cladach which means house by the shore.

Figure 12: Tygh-Na-Cladach - the first Passive House in Scotland is UK's first Affordable Housing Passivhaus (source: SPHC)

There were so many challenges to get the semi-detached house to reach Passive House criteria. The top challenge was the technical restrictions to achieve the Passive House certification, the project also had serious financial restrictions, because the future occupants who are low income are involved in the social housing scheme. Thus the final costs must be kept to be a minimum.

3.2 Climate in Dunoon

To design a Passive House, the first fact is the local climate, the first step is to know more about the climate conditions in Dunoon, and have the local climate data. Dunoon is a small town in Scotland and just over 30 miles west of Glasgow [18], along the Firth of Clyde.

Figure 13: The location of Dunoon (source: Google Map)

Although Dunoon lies at the same northerly latitude as Moscow, the town is much warmer than the Russian capital as the climate in Dunoon falls under the marine west coast category, and it is near the west coast of the Atlantic Ocean. Additionally, the Atlantic's Gulf Stream transport warm water from Mexico to the British Isles, which results in the cool summer and warm winter in Dunoon. But because of the location of Dunoon, there is significant cloud cover and fog with high humidity and precipitation amounts.

In spring, the weather is much smooth and steady. Although rainfall often happens, April, May and June are the driest months of the year, just about 2 to 3 inches of rain falling each month [18].

There is fine mist in summer time, but it’s warm, sunny, also remains dry. And July and August are the warmest months of the year, In the daytime, the highs average in the mid-60s, but at night, it falls to the bottom out in the low 50s, so need to have a sweater.

During fall time, there is always raining with wind because the low pressure systems begin rolling in off the Atlantic, especially in October. So it’s much wet in October and November. The daily high temperature is near 60 in September, and during night lows around 40s.

The winter in Dunoon is dark, damp, chilly and windy, but it’s not so cold. There is nearly no significant snowfall, but December is the wettest month of the year. The temperature in the daytime highs around 40s, and overnight lows in the middle of 30s.

In fact, the climate in Dunoon is a maritime climate with cool summers and mild winters. But it’s a wet part in UK. The table below is the climate data recorded during 1971 and 2000 by the MetOffice weather station at Benmore Botanic Gardens, around 7 miles north of Dunoon centre.

Climate data for Benmore Botanic Gardens 12m asl, 1971-2000, extremes 1960- (Weather station 7 miles (11 km) to the North of Dunoon)													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	14.4 (57.9)	14.5 (58.1)	17.2 (63.0)	23.6 (74.5)	27.0 (80.6)	28.9 (84.0)	29.6 (85.3)	29.0 (84.2)	25.1 (77.2)	21.7 (71.1)	16.5 (61.7)	14.2 (57.6)	29.6 (85.3)
Average high °C (°F)	6.5 (43.7)	6.8 (44.2)	8.6 (47.5)	11.4 (52.5)	14.9 (58.8)	16.8 (62.2)	18.4 (65.1)	18.0 (64.4)	15.3 (59.5)	12.2 (54.0)	8.9 (48.0)	7.2 (45.0)	12.1 (53.8)
Average low °C (°F)	1.0 (33.8)	1.3 (34.3)	2.2 (36.0)	3.4 (38.1)	5.8 (42.4)	8.5 (47.3)	10.7 (51.3)	10.4 (50.7)	8.6 (47.5)	6.1 (43.0)	2.9 (37.2)	1.7 (35.1)	5.22 (41.39)
Record low °C (°F)	−13.9 (7.0)	−11.1 (12.0)	−11.1 (12.0)	−4.4 (24.1)	−2.5 (27.5)	−0.6 (30.9)	2.2 (36.0)	2.6 (36.7)	−0.9 (30.4)	−4.1 (24.6)	−6.8 (19.8)	−11.5 (11.3)	−13.9 (7.0)
Precipitation mm (inches)	298.76 (11.7622)	214.43 (8.4421)	233.63 (9.198)	119.48 (4.7039)	105.12 (4.1386)	108.54 (4.2732)	127.66 (5.026)	160.85 (6.3327)	220.49 (8.6807)	257.6 (10.142)	257.82 (10.1504)	282.98 (11.1409)	2,387.36 (93.9906)

Table 2: Climate data in Dunoon during 1971 and 2000 (source: Royal Dutch Meteorological Institute/KNMI)

3.3 Technical Details of Dunoon Passive House

The Passive House in Dunoon is semi-detached house with 10 low energy houses, and 1 house was built as Passive House. There are two floors with the treated floor area is 88m^2. The construction of the house is used Prefabricated Closed Panel Timber Frame System with prefabricated floor, wall and roof cassettes pre-insulated with 80% recycled content glasswool insulation [19].

3.3.1 Building Elements

- Ambient Wall

The external walls as the main external construction of the Passive House are much important to keep the house warm and for airtightness. The walls include layers of plasterboard, PU insulation TW55, OSB, mineral wool/I-studs, softwood and OSB. The total thickness is 38.1cm, the U-value of the ambient wall is 0.086 W/(m^{2}K). The details can be seen the table as below:

Assembly No.	Building Assembly Description
1	Ambient wall

Heat Transfer Resistance [m²K/W] interior R_{si} : 0.13

exterior R_{se} : 0.13

	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	Plasterboard	0.210					13
2.	PU insulation TW55	0.021					50
3.	OSB	0.130					9
4.	Mineral wool/I-studs	0.032	softwood	0.130			50
5.	Mineral wool/I-studs	0.032			softwood	0.130	200
6.	Mineral wool/I-studs	0.032	softwood	0.130			50
7.	OSB	0.130					9
8.							
				Percentage of Sec. 2: 8.3%		Percentage of Sec. 3: 1.6%	Total: 38.1 cm

U-Value: 0.086 W/(m²K)

Table 3: Details of Ambient Wall (source: PHPP)

- Roof

The material of the roof is a little different compared to the ambient walls. It uses sarking boards with 22mm. So the final thickness of the roof is 39.4cm, and the total U-value is 0.087 W/(m^{2}K). The more details can be seen as below:

Assembly No.	Building Assembly Description
2	Roof

Heat Transfer Resistance [m²K/W] interior R_{si}: 0.10; exterior R_{se}: 0.04

	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	Plasterboard	0.210					13
2.	PU insulation TW55	0.021					50
3.	OSB	0.130					9
4.	Mineral wool/I-studs	0.032	softwood	0.130			50
5.	Mineral wool/I-studs	0.032			softwood	0.130	200
6.	Mineral wool/I-studs	0.032	softwood	0.130			50
7.	Sarking boards	0.130					22
8.							
			Percentage of Sec. 2	8.3%	Percentage of Sec. 3	1.6%	Total 39.4 cm

U-Value: 0.087 W/(m²K)

Table 4: Details of Roof (source: PHPP)

- Floor Slab

There are just two layers for floor slab, the concrete slab and insulation XPS. The total thickness is 32.5cm, and U-value is 0.154 W/(m^{2}K). Details of this part are shown in the following table:

Assembly No.	Building Assembly Description
3	Floor slab

Heat Transfer Resistance [m²K/W] interior R_{si}: 0.17; exterior Rse: 0.00

	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	Concrete slab	2.100					125
2.	Insulation XPS	0.032					200
3.							
4.							
5.							
6.							
7.							
8.							
			Percentage of Sec. 2		Percentage of Sec. 3		Total 32.5 cm

U-Value: 0.154 W/(m²K)

Table 5: Details of Floor Slab (source: PHPP)

3.3.2 Windows

For this Passive House, three kinds of glazing are used for the windows. The following table shows the details:

Type		
Glazing	g-Value	U_g-Value
		W/(m²K)
6b/10g/6/8g/b6 Front Door	0.480	0.600
6b/10g/5/10g/b6 Others	0.510	0.800
Velux Glazing	0.450	0.630

Table 6: Details of Window Glazing (source: PHPP)

There are five types of windows frame used in the Passive House. The details can be seen the table below:

Type	U_f-Value	Frame Dimensions				Thermal Bridge	Thermal Bridge
Frame	Frame	Width - Left	Width - Right	Width - Below	Width - Above	Ψ_{Spacer}	$\Psi_{Installation}$
	W/(m²K)	m	m	m	m	W/(mK)	W/(mK)
Sash Edition	0.87	0.114	0.114	0.114	0.114	0.075	0.025
Fixed Edition	0.75	0.096	0.096	0.096	0.096	0.075	0.025
Sash thick sill Edition	0.87	0.114	0.114	0.144	0.114	0.075	0.030
Fixed thick sill Edition	0.75	0.096	0.096	0.108	0.096	0.075	0.030
Velux Rooflight	1.50	0.100	0.100	0.100	0.100	0.029	0.079

Table 7: Details of Windows types (source: PHPP)

In the living room, there are three east facing windows with two sash edition and one fixed edition. Two west facing windows in kitchen, and one is sash thick sill edition, one is fixed thick sill edition. There is one sash thick sill edition window in each bedroom with west facing and east facing. Also there are three velux rooflight windows described as velux 3065 in the rood and one sash edition window for the front door. Meanwhile, each window is filled with Argon. The next table shows the details of the windows involves dimensions, g-value, U-value, ψ-value, etc.

					Window Rough Openings		g-Value	U-Value		Window Frame Dimensions				Ψ-Value	
Quan-tity	Description	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Width	Height	Perpen-dicular Radiation	Glazing	Frames	Width - Left	Width - Right	Width - Below	Width - Above	Ψ_{Spacer}	$\Psi_{Installation}$
		Degrees	Degrees		m	m	-	W/(m²K)	W/(m²K)	m	m	m	m	W/(mK)	W/(mK)
1	Living	73	90	East	0.993	2.180	0.51	0.80	0.87	0.11	0.11	0.11	0.11	0.075	0.025
1	Living	73	90	East	0.993	2.180	0.51	0.80	0.87	0.11	0.11	0.11	0.11	0.075	0.025
1	Living	73	90	East	0.994	2.180	0.51	0.80	0.75	0.10	0.10	0.10	0.10	0.075	0.025
1	Kitchen	253	90	West	1.028	2.150	0.51	0.80	0.87	0.11	0.11	0.14	0.11	0.075	0.030
1	Kitchen	253	90	West	0.952	2.150	0.51	0.80	0.75	0.10	0.10	0.11	0.10	0.075	0.030
1	Bed 1	253	90	West	0.980	2.150	0.51	0.80	0.87	0.11	0.11	0.14	0.11	0.075	0.030
1	Bed 2	73	90	East	0.980	2.150	0.51	0.80	0.87	0.11	0.11	0.14	0.11	0.075	0.030
2	Velux 3	163	45	South	0.780	1.400	0.45	0.63	1.50	0.10	0.10	0.10	0.10	0.029	0.079
1	Velux 3	343	45	North	0.780	0.980	0.45	0.63	1.50	0.10	0.10	0.10	0.10	0.029	0.079
1	Front d	163	90	South	1.080	2.080	0.48	0.60	0.87	0.11	0.11	0.11	0.11	0.075	0.025

Table 8: Details of Windows (source: PHPP)

Additionally, the following table is the results for windows sheet with area dimension, U-value and glazed fraction per window.

Results			
Window Area	Glazing Area	U-Value Window	Glazed Fraction per Window
m²	m²	W/(m²K)	%
2.2	1.49	1.06	0.69
2.2	1.49	1.03	0.69
2.2	1.59	1.03	0.74
2.2	1.51	1.06	0.68
2.0	1.48	1.04	0.72
2.1	1.42	1.10	0.68
2.1	1.42	1.10	0.68
2.2	1.39	1.36	0.64
0.8	0.45	1.45	0.59
2.2	1.58	0.93	0.70

Table 9: Results for Windows (source: PHPP)

3.3.3 Doors

The doors in the Passive House are internorm edition-Aluminium Timber Composite doors, with U-value 1.16 W/(m^{2}K). However, in this Passive House project, the porch is outside the thermal envelop including the doors and windows in the porch, thus there is no energy required.

3.3.4 Ventilation

The mechanical ventilation system is thermos 200 DC-Paul with 92% heat recovery efficiency and 0.36 Wh/m^3 of electric efficiency. It is distributed using 100-125mm diameter ducting. Thus, the final effective heat recovery efficiency is 82.1%. The details can be seen as below:

Effective Heat Recovery Efficiency of the Ventilation System with Heat Recovery

x	Central unit within the thermal envelope.						
	Central unit outside of the thermal envelope.						
	Efficiency of Heat Recovery	η_{HR}		0.92	thermos 200 DC - Paul		
	Transmittance Ambient Air Duct	Ψ	W/(mK)	0.188	Calculation see Secondary Calculation		
	Length Ambient Air Duct		m	6			
	Transmittance Exhaust Air Duct	Ψ	W/(mK)	0.188	Calculation see Secondary Calculation		
	Length Exhaust Air Duct		m	6.5		Room Temperature (°C)	20
	Temperature of Mechanical Services Room (Enter only if the central unit is outside of the thermal envelope.)		°C			Av. Ambient Temp. Heating P. (°C)	7.6
						Av. Ground Temp (°C)	11.2
Effective Heat Recovery Efficiency		$\eta_{HR,eff}$			82.1%		

Table 10: Details of Ventilation System (source: PHPP)

Nominal Width	125	mm
Insul. Thickness:	140	mm
Reflective? Please mark with an "x"!		
x	Yes	
	No	
Thermal Conductivity	0.04	W/(mK)
Nominal Air Flow Rate	67	m³/h
Δϑ	12	K
Interior Duct Diameter	0.125	m
Interior Diameter	0.125	m
Exterior Diameter	0.405	m
α-Interior	8.18	W/(m²K)
α–Surface	2.34	W/(m²K)
Ψ-value	**0.188**	**W/(mK)**
Surface Temperature Difference	1.504	K

Table 11: Secondary Calculation: Ψ-value Supply or Ambient Air Duct

3.3.5 Heating and DHW

As the house is not connected to the gas grid, an air-to-air heat pump is installed to heat the kitchen, and the heat is distributed within the house through the MVHR system.

In this Passive House, there are solar thermal collectors (4.6 m^2 Velux M08 Kollektor) and 300-l-buffer with electrical immersion heater for hot water [19].

3.3.6 Other Details

In fact, the orientation of the Passive House is undesirable, but the local climate is mild and the insulation of the shell in good. On the other hand, the space heat demand is raised because of the lack of the solar gains, but the heating load is still accepted.

3.3.7 Final Results

The next table is the verification of the Passive House, which can be seen that the specific space heat demand is 20 kWh/(m^2a), not reach the Passive House criteria.

Specific Demands with Reference to the Treated Floor Area					
Treated Floor Area:	88.4	m^2			
	Applied:	Monthly Method		PH Certificate:	Fulfilled?
Specific Space Heat Demand:	20	kWh/(m^2a)		15 kWh/(m^2a)	No
Pressurization Test Result:	0.4	h^{-1}		0.6 h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	93	kWh/(m^2a)		120 kWh/(m^2a)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	54	kWh/(m^2a)			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	0	kWh/(m^2a)			
Heating Load:	10	W/m^2			
Frequency of Overheating:	3	%	over	25 °C	
Specific Useful Cooling Energy Demand:		kWh/(m^2a)		15 kWh/(m^2a)	
Cooling Load:	8	W/m^2			

Table 12: Verification of Dunoon Passive House (source: PHPP)

3.4 Challenges of Dunoon Passive House

There were so many challenges to get the semi-detached house to reach Passive House criteria which also has mentioned in the previous part, including the technical restriction and finical restriction. Actually, there are three challenges in this Passive House project. The details will be discussed below. And the drawings of the Passive House with the south, east and west elevation can be seen below, it will be much clear to find out the challenges from the drawings.

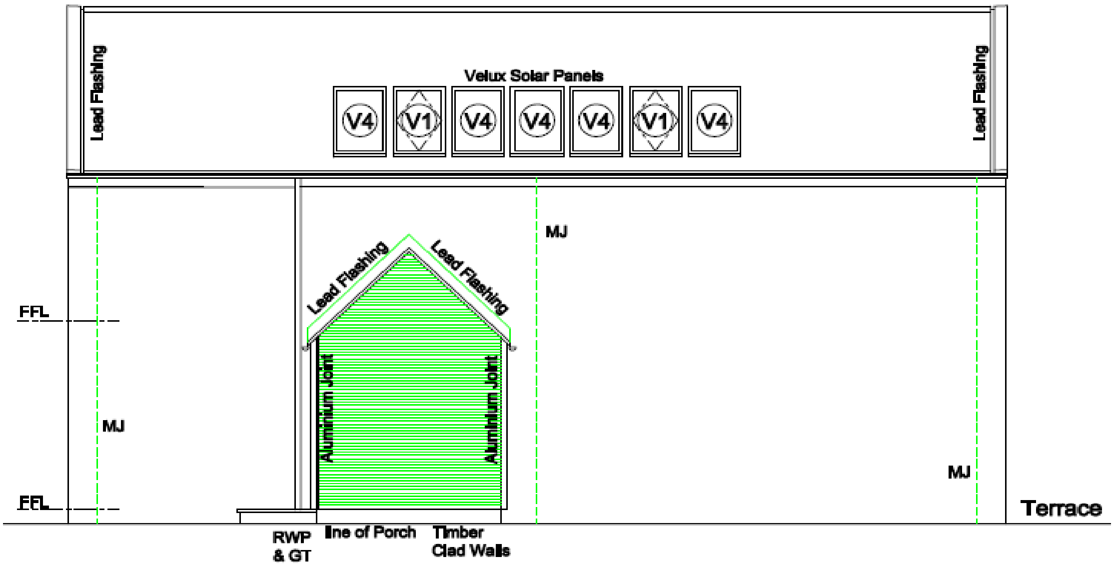

Figure 14: South Elevation of the Passive House (source: supervisor)

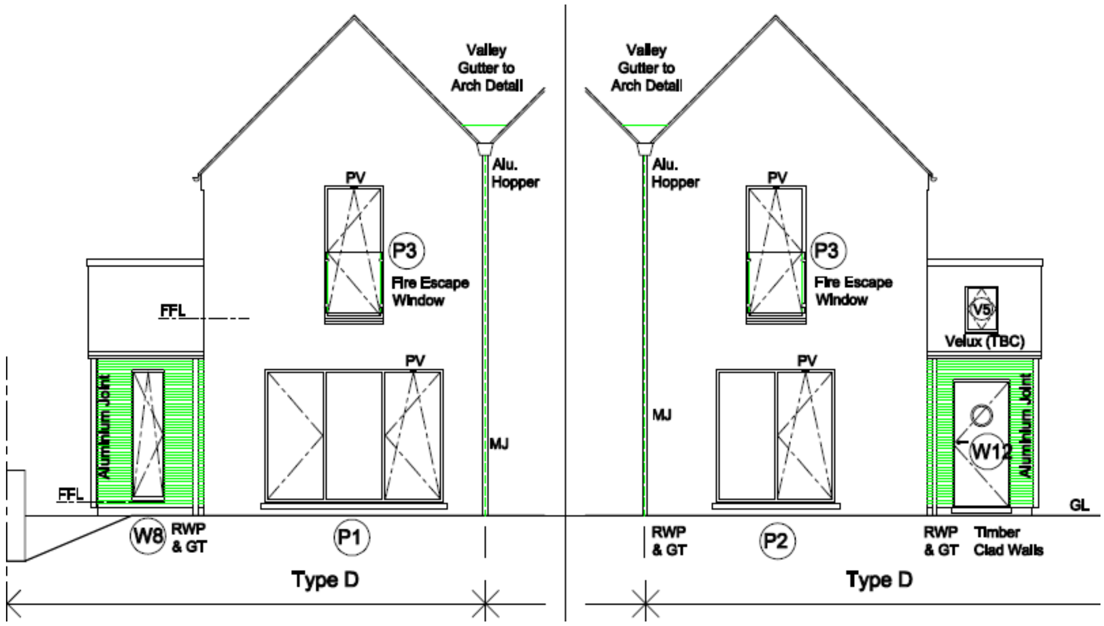

Figure 15: East and West Elevation of the Passive House (source: supervisor)

As we can see from the drawings, the first challenge is that apart from the three rooflights, there are no south facing windows, because of its location. So the solar heating gains will be very low during the year.

The next one is no gas grid connected in this area, and the solar resources in Scotland are limited, thus the electrical heating and DHW had to be installed and used in the house.

The third challenge is its long, slim and tall shape, but the floor space is small, which results in an undesirable ration between volume and area. Hence when considering the heat demand, the heat loss from the exterior surface needs to take into account.

However, in order to meet the challenges, a closed panel timber system from 'RTC Timber' was used for the shell (17). As a result, the U-values for the wall and roof were low around 0.09 W/m^2K, and the floor was about 0.12 W/m^2K. Finally the Passive House criteria were reached with the triple glazed windows and thermos 200 DC-Paul MVHR. To meet the 120 kWh/m^2a for the Passive House primary energy requirement, a solar thermal system was used to support the production of DHW, which also further reduced the energy bill for hot water by over 50%.

A mechanical ventilation with heat recovery system was installed in the Passive House, which also known as thermos 200 DC-Paul. It can be seen from the chart below, the red parts are the supply air ducts, the exact in blue, intake in green and exhaust in magenta. The fresh air is supplied in the two bedrooms and the lounge room, the kitchen and bathroom are extracted constantly. Additionally, before the extract air leaves the house, it passes by a heat exchanger which extracts the heat and also transfers it into the fresh supply sir. The MVHR is the heart of the whole system which high heat recovery rates.

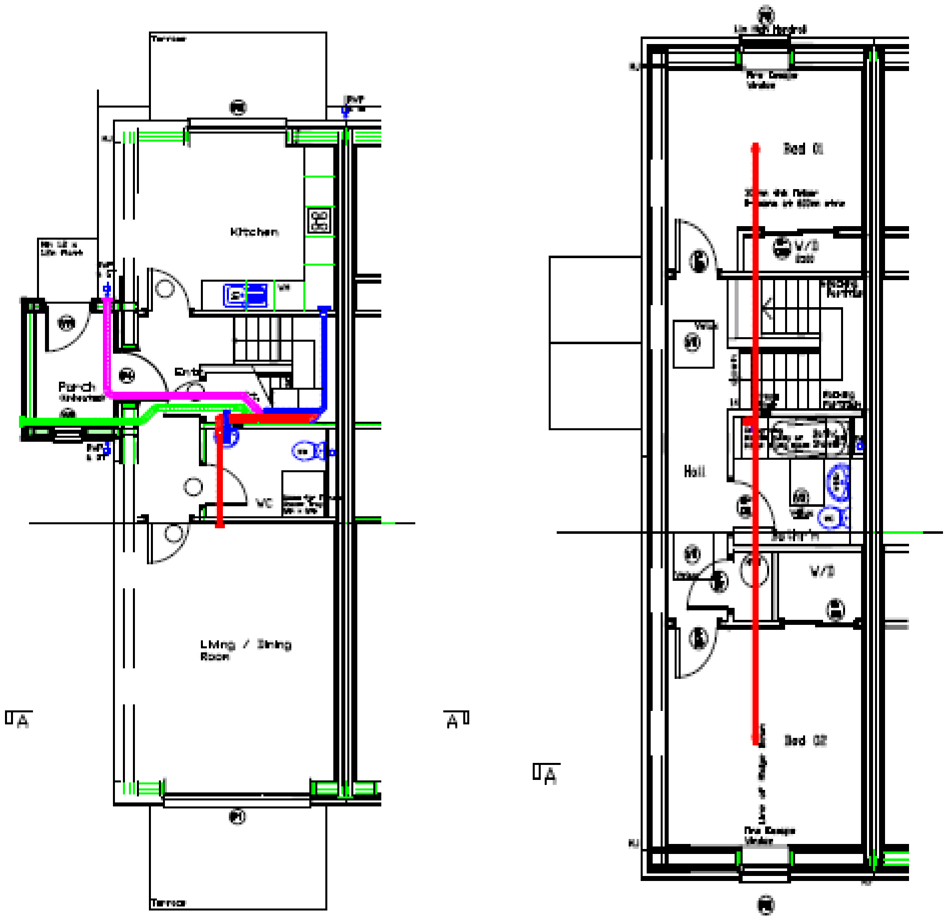

Figure 16: The ventilation ducts in ground floor (left) and first floor (right) (source: supervisor)

3.5 Feedback from Home Owner

The first Passive House in Scotland and the first affordable Passive House in the UK is owned by Karen [20]. The house has good airtightness without the traditional heating system, has solar panels which also reduce the costs by up to 50% per annum, the air to air heat pump and MVHR which ensure the fresh air in the house and extracts warmed air from kitchen and bathrooms for using again.

As what Karen has said, the performance of the Passive House is excellent, it is warmer than the average house with the temperature around 20 to 22 degrees even with the door and windows opened, and she still has not used the heating, the MVHR is amazing in practice that the house is full of fresh air even the windows are closed, the solar panels provide so much hot water.

In fact, the Passive House works well as planned, which has saved a lot of energy, and it is affordable. The successful project has confirmed that just with suitable construction, reasonable design, the Passive House can be built in any place in the world with excellent performance.

4. Methodology and Results

The Passive House in Dunoon has met the criteria, and has good performance. However, in China context, it needs to be improved again in some details, because the different climate conditions, and different living habit. Thus the following topics will be discussed in this chapter:

- **Improve the Passive House in Dunoon**
- **Introduction of the Climate Conditions in China**
- **Input the Climate Data and the Output Results**
- **More Improvement of the Passive House in China Context**

4.1 Improve the Passive House in Dunoon

As what has been discussed in the previous chapter, the performance of Dunoon Passive House is excellent, and the feedback from home owner is positive. However, the specific space heat demand of the house is 20 kWh/(m^2a), which not met the criteria of 15 kWh/(m^2a) of Passive House. Additionally, the climate conditions, environment, living habit in China are different. Thus more details need to be improved to reach better performance.

- Defrost and the Place of MVHR

First of all, column 2 of the defrosting the heat exchanger in aux electricity worksheet was changed to 0 which means it's not within the thermal envelope, because the heat is almost completely lost to the surroundings. The details can be seen as below:

Column Nr.	1	2
Application	Used ? (1/0)	Within the Thermal Envelope? (1/0)
Ventilation System		
Winter Ventilation	1	1
Summer Ventilation	0	1
Defroster HX	1	$\boxed{0}$

Table 13: Improve the Defroster HX

The next one is the place of MVHR, which was in the room center, but now it has been moved to the porch which is outside of the thermal envelope. The place of MVHR can be seen the figure below:

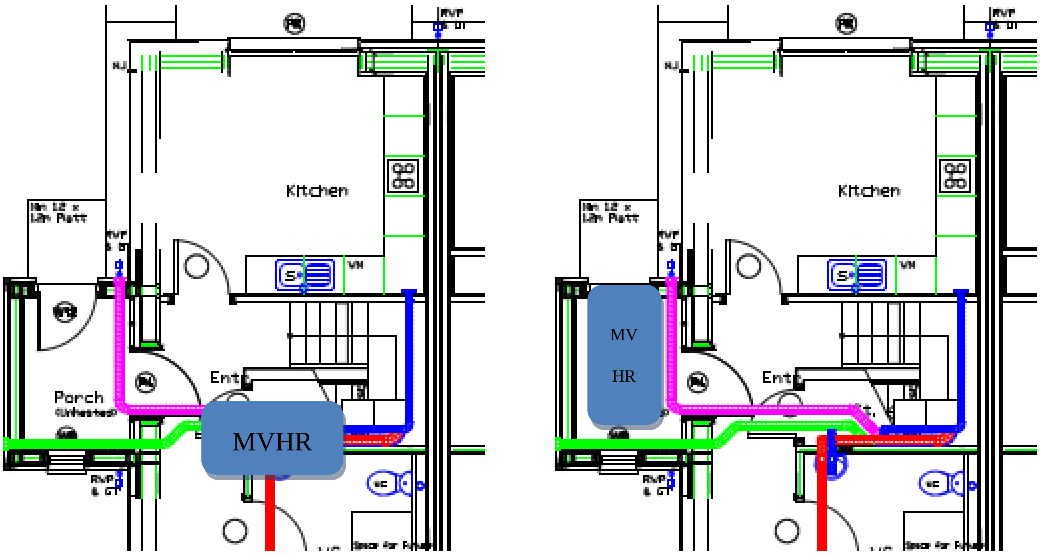

Figure 17: The Place of MVHR: previous place (left), improved place (right)

As a result, the installation location with the central unit outside of the thermal envelope is to be selected by entering an “x” in the appropriate cell. If installing the MVHR outside the thermal insulated envelope, the temperature of the installation room must be entered. Thus the temperature of the porch was assumed as 11℃. And the length of the supply air duct and the extract air duct was reduced to be 1.5m. Finally, the effective heat recovery efficiency was improved to be 90.3%, which also resulted in the specific space heat demand changed to be 19 kWh/(m^{2}a). The table below shows the details.

Effective Heat Recovery Efficiency of the Ventilation System with Heat Recovery

	Central unit within the thermal envelope.						
x	Central unit outside of the thermal envelope.						
	Efficiency of Heat Recovery	η_{HR}		0.92	thermos 200 DC - Paul		
	Transmittance Supply Air Duct	Ψ	W/(mK)	0.187	Calculation see Secondary Calculation		
	Length Supply Air Duct		m	1.5			
	Transmittance Extract Air Duct	Ψ	W/(mK)	0.187	Calculation see Secondary Calculation		
	Length Extract Air Duct		m	1.5		Room Temperature (°C)	20
	Temperature of Mechanical Services Room		°C	11		Av. Ambient Temp. Heating P. (°C)	7.6
	(Enter only if the central unit is outside of the thermal envelope.)					Av. Ground Temp (°C)	11.2
	Effective Heat Recovery Efficiency	$\eta_{HR,eff}$			90.3%		

Table 14: Improved MVHR

- Windows

If the Dunoon Passive House is moved into China context, there is no location restriction, which means the south-facing windows can be created. So the heat gains will be increased, but it also will have some problems if the house in China context, the details will be discussed later.

So in the south side of the Passive House, six windows were created with the same material, size and the frame. In the living room, there are three south-facing windows with two sash edition and one is fixed edition. In each bedroom, one south facing window was created with sash thick sill edition. Meanwhile, in the kitchen there is one south facing window with sash thick sill edition as well. The details can be seen below:

					Window Rough Openings		Installation				Results			
Quan-tity	Description	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Width	Height	Left 1/0	Right 1/0	Sill 1/0	Head 1/0	Window Area	Glazing Area	U-Value Window	Glazed Fraction per Window
		Degrees	Degrees		m	m					m^2	m^2	$W/(m^2K)$	%
1	Living room	73	90	East	0.993	2.180	1	0	1	1	2.2	1.49	1.06	0.69
1	Living room	73	90	East	0.993	2.180	0	0	1	1	2.2	1.49	1.03	0.69
1	Living room	73	90	East	0.994	2.180	0	1	1	1	2.2	1.59	1.03	0.74
1	Kitchen	253	90	West	1.028	2.150	1	0	1	1	2.2	1.51	1.06	0.68
1	Kitchen	253	90	West	0.952	2.150	0	1	1	1	2.0	1.48	1.04	0.72
1	Bed 1	253	90	West	0.980	2.150	1	1	1	1	2.1	1.42	1.10	0.68
1	Bed 2	73	90	East	0.980	2.150	1	1	1	1	2.1	1.42	1.10	0.68
2	Velux 3065 M08	163	45	South	0.780	1.400	1	1	1	1	2.2	1.39	1.36	0.64
1	Velux 3065 M04	343	45	North	0.780	0.980	1	1	1	1	0.8	0.45	1.45	0.59
1	Front door	163	90	South	1.080	2.080	1	1	1	1	2.2	1.58	0.93	0.70
1	Living room	163	90	South	0.993	2.180	1	0	1	1	2.2	1.49	1.06	0.69
1	Living room	163	90	South	0.993	2.180	0	0	1	1	2.2	1.49	1.03	0.69
1	Living room	163	90	South	0.994	2.180	0	1	1	1	2.2	1.59	1.03	0.74
1	Bed 2	163	90	South	0.980	2.150	1	1	1	1	2.1	1.42	1.10	0.68
1	Bed 1	163	90	South	0.980	2.150	1	1	1	1	2.1	1.42	1.10	0.68
1	Kitchen	163	90	South	1.028	2.150	1	1	1	1	2.2	1.51	1.09	0.68

Table 15: Improvement of Windows

In the installation sheet, if the corresponding jamb has direct contact with the building envelope, the installation factor is “1”, it is “0” is two windows are abutted symmetrically against each other.

Until now, in the verification sheet, the performance of the Passive House has been mended. It can be seen below, the specific space heat demand has changed to be 15 kWh/(m^2a) which has met the standard. The specific primary energy demand has been decreased at the same time, and other criteria have been improved as well. But it's still not enough, such as the frequency of overheating is much higher, the improvement continued.

Specific Demands with Reference to the Treated Floor Area					
Treated Floor Area:	88.4	m^2			
	Applied:	Monthly Method	PH Certificate:		Fulfilled?
Specific Space Heat Demand:	15	$kWh/(m^2a)$	15	$kWh/(m^2a)$	Yes
Pressurization Test Result:	0.4	h^{-1}	0.6	h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	90	$kWh/(m^2a)$	120	$kWh/(m^2a)$	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	51	$kWh/(m^2a)$			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	0	$kWh/(m^2a)$			
Heating Load:	11	W/m^2			
Frequency of Overheating:	24	%	over 25	°C	
Specific Useful Cooling Energy Demand:		$kWh/(m^2a)$	15	$kWh/(m^2a)$	
Cooling Load:	16	W/m^2			

Table 16: Verification of the Passive House after the improvement of MVHR and Windows

- Shading

Because more windows were installed in the Passive House, the improvement of shading is required as well, especially the shading by window reveals needs to be considered.

In this worksheet, r_H is the shading by a row of houses directly in front of the considered window, r_R means the shading by reveals or other vertical elements, and r_O is the shading by cantilevered horizontal elements above the window such as balcony slabs. So the shading factor, r_S is calculated with the following formula:

$$r_S = r_H \cdot r_R \cdot r_O \cdot r_{ot}$$

The shading by window reveals is the main factor in this Passive House. The window reveal depth is measured from the exterior wall to the glazing surface, the average window-frame width can be calculated from the entered window geometries. The details can be seen in the following table.

Quantity	Description	Glazing Width	Glazing Height	Glazing Area	Height of the Shading Object	Horizontal Distance	Window Reveal Depth	Distance from Glazing Edge to Reveal	Overhang Depth	Distance from Upper Glazing Edge to Overhang	Horizontal Shading Reduction Factor	Reveal Shading Reduction Factor	Overhang Shading Reduction Factor	Total Shading Reduction Factor
		m	m		m	m	m	m	m	m	%	%	%	%
		w_G	h_G	A_G	h_{Hori}	d_{Hori}	o_{Reveal}	d_{Reveal}	o_{over}	d_{over}	r_H	r_R	r_O	r_S
1	Living room	0.77	1.95	1.5	1.20	10.00	0.15	0.080	0.15	0.08	89%	87%	96%	74%
1	Living room	0.77	1.95	1.5	1.20	10.00	0.15	0.080	0.15	0.08	89%	87%	96%	74%
1	Living room	0.80	1.99	1.6	1.20	10.00	0.13	0.040	0.15	0.08	89%	88%	96%	75%
1	Kitchen	0.80	1.89	1.5	25.00	20.00	0.15	0.080	0.15	0.08	33%	87%	96%	28%
1	Kitchen	0.76	1.95	1.5	25.00	20.00	0.13	0.040	0.15	0.08	33%	87%	96%	28%
1	Bed 1	0.75	1.89	1.4	21.00	20.00	0.15	0.080	0.15	0.08	38%	87%	96%	32%
1	Bed 2	0.75	1.89	1.4			0.15	0.08	0.15	0.08	100%	86%	96%	83%
2	Velux 3065 M08	0.58	1.20	1.4			0.01	0.00	0.03	0.00	100%	99%	100%	99%
1	Velux 3065 M04	0.58	0.78	0.5			0.01	0.00	0.03	0.00	100%	99%	97%	96%
1	Front door	0.85	1.85	1.6	2.75	1.50	0.15	0.08	1.50	0.10	9%	94%	87%	7%
1	Living room	0.77	1.95	1.5			0.15	0.08	0.15	0.08	100%	93%	99%	92%
1	Living room	0.77	1.95	1.5			0.15	0.08	0.15	0.08	100%	93%	99%	92%
1	Living room	0.80	1.99	1.6			0.13	0.04	0.15	0.08	100%	94%	99%	93%
1	Bed 2	0.75	1.89	1.4			0.15	0.08	0.15	0.08	100%	93%	99%	92%
1	Bed 1	0.75	1.89	1.4			0.15	0.08	0.15	0.08	100%	93%	99%	92%
1	Kitchen	0.80	1.89	1.5			0.15	0.08	0.15	0.08	100%	94%	99%	92%

Table 17: Improvement of Shading

However, after improving the shading, the specific space heat demand has increased to be 16 kWh/(m^2a), as the shading decreases the heat gains.

- Cooking with Gas and MVHR-Paul Focus 200

In the Dunoon Passive House, there is no gas grid connected. However, in China, gas grid in connected in most of the houses. Thus, in electricity sheet, cooking with gas was chosen, which also resulted in decreasing the specific primary energy demand.

The next change is the MVHR which chooses Paul Focus 200 instead of Paul Thermos 200 DC. And the size of the newer MVHR is much smaller, which will save more space in the porch. The heat recovery efficiency is 91%, the electric efficiency is 0.31 Wh/m^3. More details of Paul Focus 200 can be seen in appendix. As a result, the effective heat recovery efficiency was decreased to be 89.4%. Details are shown below:

Effective Heat Recovery Efficiency of the Ventilation System with Heat Recovery						
	Central unit within the thermal envelope.					
x	Central unit outside of the thermal envelope.					
	Efficiency of Heat Recovery	η_{HR}		0.91	Paul Focus 200	
	Transmittance Supply Air Duct	Ψ	W/(mK	0.187	Calculation see Secondary Calculation	
	Length Supply Air Duct		m	1.5		
	Transmittance Extract Air Duct	Ψ	W/(mK	0.187	Calculation see Secondary Calculation	
	Length Extract Air Duct		m	1.5	Room Temperature (°C)	20
	Temperature of Mechanical Services Room		°C	11	Av. Ambient Temp. Heating P. (°C)	7.6
	(Enter only if the central unit is outside of the thermal envelope.)				Av. Ground Temp (°C)	11.2
Effective Heat Recovery Efficiency		$\eta_{HR,eff}$			89.4%	
Effective Heat Recovery Efficiency Subsoil Heat Exchanger						
	SHX Efficiency	η^*_{SHX}		0%		
	Heat Recovery Efficiency SHX	η_{SHX}		0%		

Table 18: Improvement of MVHR

- Remove Roof Windows and Windows in Living and Kitchen Room

The results of verification in the previous table have shown that the frequency of overheating is 24% which is much higher, because of the created windows in the south side of the house.

The window in the roof is one fact, and which also will increase heat loss. Thus, they were removed. On the other hand, one window is enough in the east side of living room, and one window kept in the west side of kitchen. After that, the frequency of overheating was improved to be 6%. It can be seen below:

Specific Demands with Reference to the Treated Floor Area					
Treated Floor Area:	88.4	m²			
	Applied:	Monthly Method		PH Certificate:	Fulfilled?
Specific Space Heat Demand:	13	kWh/(m²a)		15 kWh/(m²a)	Yes
Pressurization Test Result:	0.4	h^{-1}		0.6 h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	81	kWh/(m²a)		120 kWh/(m²a)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	47	kWh/(m²a)			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	0	kWh/(m²a)			
Heating Load:	9	W/m²			
Frequency of Overheating:	6	%	over	25 °C	
Specific Useful Cooling Energy Demand:		kWh/(m²a)		15 kWh/(m²a)	
Cooling Load:	10	W/m²			

Table 19: Verification of Passive House after improving more details

- Summvent and PE Value

At last, summvent was added to decrease more of the frequency of overheating. In summvent worksheet, it allows for an estimate of the air flow rate through defined window opening configurations for summertime indoor conditions.

First of all, the fraction of opening duration can be entered, because the windows normally does not keep open during the entire day, a percentage of the opening time can be defined which will be multiplied with the calculated air change in the end.

Then the climate boundary conditions are entered. A typical value of 4K can be used for the difference in temperature, as the window is used for air exchange all day long, not only for cooling the building down at night. And the reasonable value of 1m/s is assumed for wind velocity, because the velocity of wind is not very high at many locations.

Next is the window specifications entered in to window group 1. Because only one-side ventilation through an individual window or multiple adjacent windows on the same side of the building. The following table shows the details.

Description	Day K	Day L	Day B	Night			
Fraction of Opening Duration	50%	50%	13%	50%			
Climate Boundary Conditions							
Temperature Diff Interior - Exterior	4	4	4	1			K
Wind Velocity	1	1	1	0			m/s
Window Group 1							
Quantity	2	3	4	4			
Clear Width	0.81	0.77	0.76	0.76			m
Clear Height	2.15	2.18	2.15	2.15			m
Tilting Windows?	x	x	x	x			
Opening Width (for tilting windows)	0.050	0.050	0.050	0.050			m
Window Group 2 (Cross Ventilation)							
Quantity							
Clear Width							m
Clear Height							m
Tilting Windows?							
Opening Width (for Tilting Windows)							m
Difference in Height to Window 1							m
Single-Sided Ventilation 1 - Airflow Volume	82	123	160	78	0	0	m³/h
Single-Sided Ventilation 2 - Airflow Volume	0	0	0	0	0	0	m³/h
Cross Ventilation Airflow Volume	82	123	160	78	0	0	m³/h
Contribution to Air Change Rate	0.18	0.28	0.09	0.18	0.00	0.00	1/h

Table 20: Details of Summvent

Thus, the average air change rate of nighttime window ventilation is 0.18 1/h, and 0.55 1/h of daytime window ventilation, which can be seen as below:

Description Ventilation Type	Daily Average Air Change Rate	
Nighttime Window Ventilation	0.18	1/h
Daytime Window Ventilation	0.55	1/h
		1/h

Table 21: Summary of Summer Ventilation Distribution

Additionally, in China context, boiler is used for space heating, and DHW. So in PE value worksheet, it has been changed as below:

Boiler			PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heat Demand	*(Project)*	100%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand	*(Project)*	100%	1.1	250
Boiler Type	*(Boiler worksheet)*	Condensing Boiler Gas		
Utilisation Factor Heat Generator	*(Boiler worksheet)*	71%		
Annual Energy Demand (without DHW Wash&Dish)	*(Boiler worksheet)*	27.6	30.3	6.9
Non-Electric Demand, DHW Wash&Dish	*(Electricity worksheet)*	1.6	1.7	0.4
Total Heating Oil/Gas/Wood		**29.1**	**32.0**	**7.3**

Table 22: Improvement of PE Value

Until now, the improvement of the Dunoon Passive House has been finished. The following table of verification showed the final achievement after improving the windows, shading, MVHR, summvent, etc. And now the performance of the Passive House is much better, and it can be used as a model in China context.

Specific Demands with Reference to the Treated Floor Area					
Treated Floor Area:	88.4	m²			
	Applied:	Monthly Method		PH Certificate:	Fulfilled?
Specific Space Heat Demand:	**13**	**kWh/(m²a)**		**15 kWh/(m²a)**	**Yes**
Pressurization Test Result:	**0.4**	**h^{-1}**		0.6 h^{-1}	**Yes**
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	**75**	**kWh/(m²a)**		120 kWh/(m²a)	**Yes**
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	**43**	**kWh/(m²a)**			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	**0**	**kWh/(m²a)**			
Heating Load:	**9**	**W/m²**			
Frequency of Overheating:	**2**	**%**	over	25 °C	
Specific Useful Cooling Energy Demand:		**kWh/(m²a)**		15 kWh/(m²a)	
Cooling Load:	**10**	**W/m²**			

Table 23: Final Verification of the Passive House

4.2 Introduction of the Climate Conditions in China

It was mentioned in the previous chapter, to design a Passive House, the first fact is the local climate. Thus it is necessary to be familiar with the climate conditions in China, and get the climate data in China. As China has a vast territory about 9,600,000 km^2, which is close to the whole Europe, the climate is very diverse. There are extremely warm as well as extremely cold conditions in China, because of the monsoon winds, which also affect the rainfall. Additionally, the altitude, latitude and longitudinal location also affect the climate.

In the north during December and March, it is winter, which is incredibly cold. Such as in Beijing the temperature is just around 0℃, and in Inner Mongolia or Heilongjiang, it is much colder. In the summer time during May and August, the temperature in Beijing is above 37.7℃ with much more rain. The best time there is Spring and Autumn with the temperature around 25℃ and less rain.

In the central of China, summer is long, hot and humid. Especially Wuhan, Chongqing and Nanjing are dubbed as the three furnaces. It can also be wet at any time other than summer. In winter, it is short and cold with temperature below freezing, which is nearly as cold as Beijing.

In the far south near Guangzhou, the summer time is hot and humid, and the temperature can rise to 37.7℃. Between July and September, typhoons are always hit the southeast coast, which bring a lot of rain. From January and March is the short winter which is warmer than north. However, this region can be miserably wet and cold with perpetual rain and drizzle.

In the northwest of China, it has a hot summer with temperature around 47.7℃ in Urumqi and Turpan. But the winter is much cold as north of China.

It can be seen from the map below, the climate conditions in China can be divided into several zones. It is very different from Europe’s ocean climate which is wet and warm. Cold zone in the north including Beijing, hot summer and cold winter zone in the central including Shanghai, hot summer and warm winter zone in south including Hong Kong, etc [21]. Because Beijing, Shanghai and Hong Kong are the economic and culture centers in China, and they are in three different climate zones, in this project these three cities are selected as the locations of the Passive House.

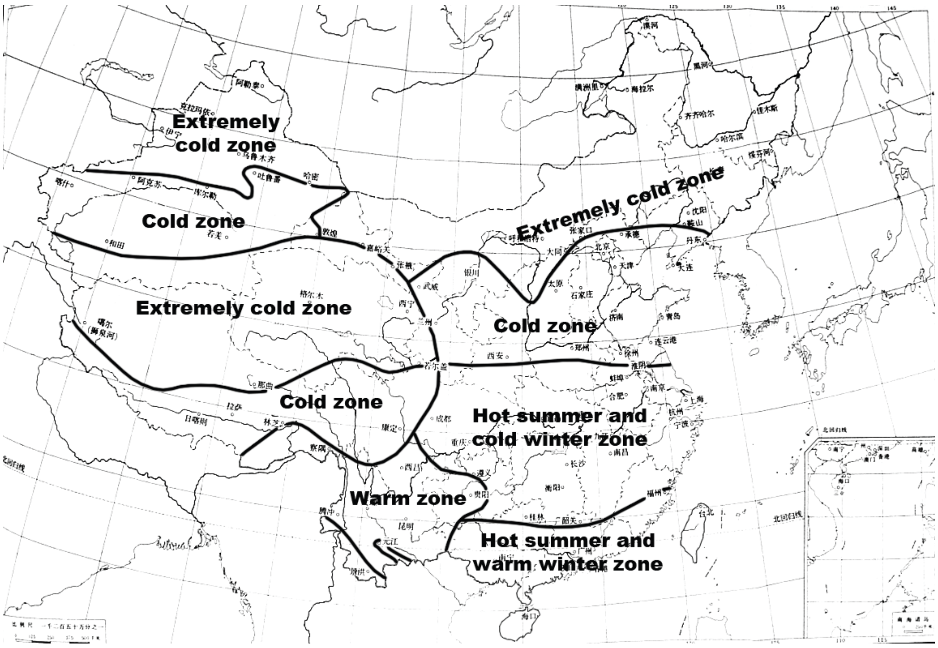

Figure 18: Different climate zones of China (source: Code for design of civil buildings, GB 50352-2005)

4.3 Input the Climate Data and the Output Results

The locations of Passive House have been decided, which are Beijing, Shanghai and Hong Kong in three different climate zones. The next step is to get the climate data in these three countries and input into PHPP. The climate data tool in passipedia can be used to find out the climate data in any cities. Thus, the data can be seen as below in the three countries.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Heating Load		Cooling Load
Days	31	28	31	30	31	30	31	31	30	31	30	31	Weather 1	Weather 2	Radiation
Beijing	Latitude:	39.9	Longitude ° East	116.4	Altitude m	247	Daily Temperature Swing Summer (K)			9.9			Heating Load	eating Load	Cooling Load
Ambient Temp	-8.0	-3.9	3.4	12.9	19.7	23.5	24.2	22.8	18.9	12.0	2.3	-5.1	-13.4	-9.9	29.4
North	17	20	29	34	43	47	45	38	30	24	18	16	25	22	84
East	56	64	86	96	100	90	83	78	73	69	56	52	83	44	179
South	160	149	145	115	92	78	77	88	110	143	148	157	235	111	145
West	58	65	87	96	100	90	83	78	73	69	56	54	83	44	179
Global	85	105	147	174	192	176	162	147	131	114	85	76	131	81	331
Dew Point	-8.0	-4.6	-7.2	-5.2	2.2	10.6	16.8	16.0	8.4	-0.6	-4.7	-5.1			
Sky Temp	-25.5	-21.8	-13.6	-3.5	4.2	11.3	15.1	13.1	5.2	-4.5	-15.5	-23.0			
Ground Temp	8.1	6.7	6.8	8.5	12.2	15.3	18.0	19.5	19.3	16.8	14.0	10.8	10.2	10.2	19.5

Table 24: Climate data in Beijing

Month	1	2	3	4	5	6	7	8	9	10	11	12	Heating Load		Cooling Load
Days	31	28	31	30	31	30	31	31	30	31	30	31	Weather 1	Weather 2	Radiation
Shanghai	Latitude:	31.2	Longitude ° East	121.5	Altitude m	5	Daily Temperature Swing Summer (K)			6.6			Heating Load	eating Load	Cooling Load
Ambient Temp	5.1	6.1	9.3	14.2	18.7	22.6	26.1	25.9	22.9	18.1	13.0	7.4	2.8	6.6	29.1
North	27	29	37	43	52	52	56	50	41	35	28	26	25	19	85
East	47	51	62	71	80	73	86	82	69	61	50	48	55	24	171
South	99	89	82	70	62	53	63	73	83	97	100	108	127	30	125
West	48	51	62	71	80	73	86	82	69	61	50	48	55	24	171
Global	80	88	110	130	150	138	163	151	124	105	84	80	105	49	333
Dew Point	1.0	1.6	4.8	10.0	14.8	19.7	23.5	23.3	19.3	13.4	8.3	2.8			
Sky Temp	-8.3	-6.3	-1.8	3.9	9.4	15.3	19.8	19.3	14.4	7.2	0.7	-6.0			
Ground Temp	14.4	13.4	13.5	14.6	17.3	19.4	21.1	22.0	21.9	20.8	18.2	16.1	10.2	10.2	22.0

Table 25: Climate data in Shanghai

Month	1	2	3	4	5	6	7	8	9	10	11	12	Heating Load		Cooling Load
Days	31	28	31	30	31	30	31	31	30	31	30	31	Weather 1	Weather 2	Radiation
Hongkong	Latitude:	22.4	Longitude ° East	114.1	Altitude m	35	Daily Temperature Swing Summer (K)			6.0			Heating Load	eating Load	Cooling Load
Ambient Temp	15.5	16.8	19.5	22.5	24.7	26.1	26.3	26.4	25.6	24.0	20.9	16.8	7.7	11.6	28.2
North	34	32	40	44	53	57	60	50	45	43	36	34	38	24	96
East	54	46	52	61	71	72	82	77	71	73	65	56	77	24	147
South	93	65	59	53	51	47	52	59	74	102	113	103	145	32	124
West	54	47	53	61	71	72	83	77	71	73	65	56	77	24	147
Global	96	84	97	114	135	138	158	146	133	133	114	99	159	56	296
Dew Point	8.8	11.0	14.4	18.9	21.9	23.9	24.2	24.0	22.2	17.5	13.0	8.8			
Sky Temp	5.4	8.3	12.5	16.4	18.7	20.6	20.4	20.6	18.9	14.7	9.8	5.1			
Ground Temp	21.9	21.4	21.4	22.0	23.0	24.0	25.0	25.5	25.4	24.8	23.9	22.8	10.2	10.2	25.5

Table 26: Climate data in Hong Kong

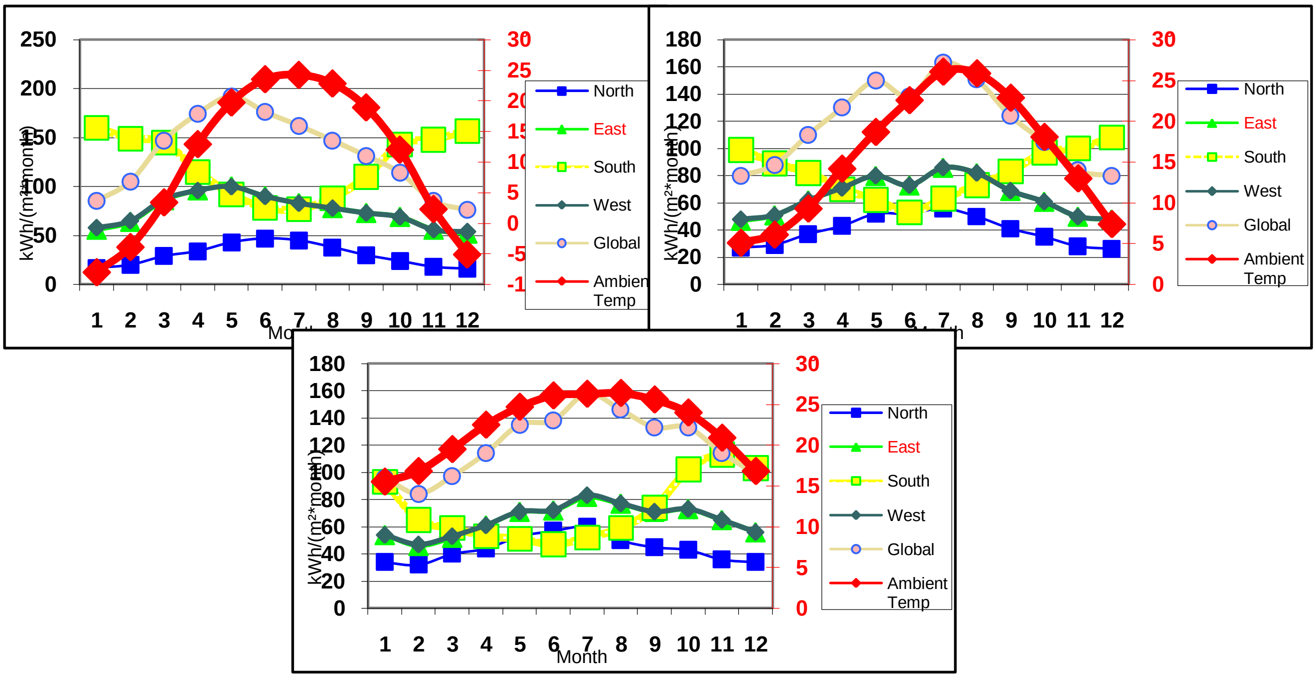

Figure 19: Climate data in the three countries (top left: Beijing; top right: Shanghai; bottom: Hong Kong)

After inputting the climate data into PHPP, the verification showed the final results of the Passive House in Beijing. It can be seen in the following table, the specific space heat demand is 11 kWh/(m^{2}a) which reaches the criteria. However, the frequency of overheating is 42%, which is a big problem needs to be solved.

Specific Demands with Reference to the Treated Floor Area				
Treated Floor Area:	88.4	m^2		
	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	11	kWh/(m^{2}a)	15 kWh/(m^{2}a)	Yes
Pressurization Test Result:	0.4	h^{-1}	0.6 h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	58	kWh/(m^{2}a)	120 kWh/(m^{2}a)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	27	kWh/(m^{2}a)		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	0	kWh/(m^{2}a)		
Heating Load:	12	W/m^2		
Frequency of Overheating:	42	%	over 25 °C	
Specific Useful Cooling Energy Demand:		kWh/(m^{2}a)	15 kWh/(m^{2}a)	
Cooling Load:	14	W/m^2		

Table 27: Verification of Passive House in Beijing

The next table is the results of Passive House in Shanghai, the space heat demand is much better, but the frequency of overheating is also a problem as Beijing.

Specific Demands with Reference to the Treated Floor Area				
Treated Floor Area:	88.4	m^2		
	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	2	$kWh/(m^2a)$	15 $kWh/(m^2a)$	Yes
Pressurization Test Result:	0.4	h^{-1}	0.6 h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	57	$kWh/(m^2a)$	120 $kWh/(m^2a)$	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	26	$kWh/(m^2a)$		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	0	$kWh/(m^2a)$		
Heating Load:	6	W/m^2		
Frequency of Overheating:	47	%	over 25 °C	
Specific Useful Cooling Energy Demand:		$kWh/(m^2a)$	15 $kWh/(m^2a)$	
Cooling Load:	14	W/m^2		

Table 28: Verification of Passive House in Shanghai

The results of the Passive House in Hong Kong can be seen in the next table, which has shown that it has a good performance of space heat demand. Yet the frequency of overheating is much worse about 85%.

Specific Demands with Reference to the Treated Floor Area				
Treated Floor Area:	88.4	m^2		
	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	0	$kWh/(m^2a)$	15 $kWh/(m^2a)$	Yes
Pressurization Test Result:	0.4	h^{-1}	0.6 h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	51	$kWh/(m^2a)$	120 $kWh/(m^2a)$	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	19	$kWh/(m^2a)$		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	0	$kWh/(m^2a)$		
Heating Load:	3	W/m^2		
Frequency of Overheating:	85	%	over 25 °C	
Specific Useful Cooling Energy Demand:		$kWh/(m^2a)$	15 $kWh/(m^2a)$	
Cooling Load:	13	W/m^2		

Table 29: Verification of Passive House in Hong Kong

As a result, the Passive House in China does not have the desirable performance, especially in summer. The frequency of overheating is a big problem in any kind of climate zones. To reach the goals of this project, more details of the Passive House need to be improved to reduce the overheating.

4.4 More Improvement of the Passive House in China Context

In this chapter, more improvement will be applied in the Passive House in PHPP to reach the standard, as the results of Passive House in China are not desirable. Hence, the summer ventilation, shading and so on should be considered. Especially in the summer time, the solar radiation is much stronger, and it will lead to an increase in air temperature and mean radiant temperature. On the other hand, the radiation from direct sun can cause discomfort glare.

Therefore, the shading devices should be installed in the Passive House to avoid such influences. The devices can be classified into three types.

1. Moveable opaque such as roller blinds, curtain, etc, can reduce solar gains with highly effect, but will eliminate view and impede air movement.
2. Louvres are removable, adjustable, fixed-affect view, and air movement to some degree, also will provide security.
3. Fixed overhangs like overhang roof or balcony are reliable to protect walls and openings from rain, nearly no effect on view and air movement [22].

In practice, the shading devices can be varied in form and can be combined with the above types.

Additionally, the overheating limit temperature should be considered. For the health and saving energy, the difference in temperature inside and outside should be around 8℃-10℃. And the temperature in summer time in China is much higher, hence 26℃-28℃ is a comfort temperature period in China. And the following chapter will discuss the details of improvement in the three cities in China.

4.4.1 Improvement of Passive House in Beijing

Beijing is in the north of China in the cold zone, thus the overheating limit temperature changed to 26℃. And the air change rate by nature or exhaust-only mechanical ventilation in summer changed to be 0.18 1/h, which is provided from summvent worksheet and achievable by window ventilation.

In summer time, the shading conditions have influence on summer comfort, therefore the temporary shading reduction factor, z, needs to be taken into account. It can be applied into any kinds of windows, and provides the relation between windows with and without shading devices. The value z=100% means no shading devices, and z=0% is total shading. The following table shows some typical reduction factors only applicable to low-e triple glazing.

Type of Shading Device	Exterior position	Interior position
Blinds, vertical lamellas:	0.06	0.7
Blinds, lamellas 45° :	0.1	0.75
Roller blinds/marquees, white	0.24	0.6
Roller blinds/marquees, grey	0.12	0.8
Foil	-	0.6

Table 30: Reduction factors for typical temporary shading devices with low-e triple glazing according to DIN V 18599-2 (source: PHPP manual)

So the roller blinds/marquees, white are applied in exterior position in the Passive House in Beijing, and the temporary shading reduction factor is 24%. Finally, the verification of the Passive House in Beijing has met the criteria, with the 6% frequency of overheating. It can be seen below:

Specific Demands with Reference to the Treated Floor Area				
Treated Floor Area:	88.4	m^2		
	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	11	$kWh/(m^2a)$	15 $kWh/(m^2a)$	Yes
Pressurization Test Result:	0.4	h^{-1}	0.6 h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	58	$kWh/(m^2a)$	120 $kWh/(m^2a)$	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	27	$kWh/(m^2a)$		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	0	$kWh/(m^2a)$		
Heating Load:	12	W/m^2		
Frequency of Overheating:	6	%	over 26 °C	
Specific Useful Cooling Energy Demand:		$kWh/(m^2a)$	15 $kWh/(m^2a)$	
Cooling Load:	7	W/m^2		

Table 31: Final verification of Passive House in Beijing

4.4.2 Improvement of Passive House in Shanghai

Shanghai is in the central of China in the hot summer and cold winter zone, hence the overheating limit temperature is assumed as 28℃, and the air change rate by nature or exhaust-only mechanical ventilation in summer also improved as 0.18 1/h. The shading devices also selected the roller blinds/marquees, white in exterior position with the temporary shading reduction factor is 24%, which is the same in Beijing. The following table showed that the Passive House in Shanghai has a good performance with the improved frequency of overheating just about 9%.

Specific Demands with Reference to the Treated Floor Area				
Treated Floor Area:	88.4	m^2		
	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	2	$kWh/(m^2a)$	15 $kWh/(m^2a)$	Yes
Pressurization Test Result:	0.4	h^{-1}	0.6 h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	57	$kWh/(m^2a)$	120 $kWh/(m^2a)$	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	26	$kWh/(m^2a)$		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	0	$kWh/(m^2a)$		
Heating Load:	6	W/m^2		
Frequency of Overheating:	9	%	over 28 °C	
Specific Useful Cooling Energy Demand:		$kWh/(m^2a)$	15 $kWh/(m^2a)$	
Cooling Load:	5	W/m^2		

Table 32: Final verification of Passive House in Shanghai

4.4.3 Improvement of Passive House in Hong Kong

Because Hong Kong is in the hot summer and warm winter zone, the overheating is more serious than other cities. First of all, the overheating limit temperature also changed as 28℃. Next in the summvent worksheet, the fraction of opening during at night is increased to be 75%, thus the air change rate is changed to be 0.2 1/h. The shading devices are roller blinds/marquees, grey in exterior position with the 12% temporary shading reduction factor. However, it is still not enough to reduce the overheating. Therefore, additional shading reduction factor (summer) is considered to improve, such as the shading by deciduous trees. So it is assumed to plant trees in the front of the east and west side windows, and the value of r_{other} is assumed as 20% which is just applied to the east and west side windows. At last, the Passive House in Hong Kong has a desirable performance until now, which can be seen the table below. It has the 0 kWh/(m^{2}a) of specific space heat demand and 8% of frequency of overheating.

Specific Demands with Reference to the Treated Floor Area				
Treated Floor Area:	88.4	m^2		
	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	0	kWh/(m^{2}a)	15 kWh/(m^{2}a)	Yes
Pressurization Test Result:	0.4	h^{-1}	0.6 h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	51	kWh/(m^{2}a)	120 kWh/(m^{2}a)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	19	kWh/(m^{2}a)		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	0	kWh/(m^{2}a)		
Heating Load:	3	W/m^2		
Frequency of Overheating:	8	%	over 28 °C	
Specific Useful Cooling Energy Demand:		kWh/(m^{2}a)	15 kWh/(m^{2}a)	
Cooling Load:	3	W/m^2		

Table 33: Final verification of Passive House in Hong Kong

Until now, the Passive House in Beijing, Shanghai and Hong Kong has a satisfactory performance. It has proved that the Passive House is feasibility with the climate conditions in China.

5. Analysis

The Passive House is feasibility with the climate conditions in China. But there are still some limitations about environment, culture, legislation, etc. Therefore in this chapter, the following topics will be discussed to evaluate the feasibility of Passive House in China context deeply:

- **The Situation of Environment and Energy in China**
- **The Limitation of Passive House in China**
- **Summary**

5.1 The Situation of Environment and Energy in China

China is developing faster and faster, which lead to serious environment problems, and energy crisis. Along with the growth of population, energy consumption is larger and larger, unreasonable utilization of energy also results in more waste, and environmental problems. The Passive House is green, clean and can save more energy, which have been proved in the previous chapters. Thus it should be encouraged and spread in China to face to the environment and energy problems. First of all, more details of such problems need to be perceived, and then the Passive House can adapt the environment and protect it.

5.1.1 Energy Situation and Problems in China

The People's Republic of China's electric power industry has changed greatly since the early 1990s especially when China entered into WTO, and has become the world's second largest electricity consumer. The energy resources in China are abundant with the world's third largest coal reserves and massive hydroelectric resources. As a result, the main types of electricity generation in China are thermal power generation, hydropower generation and nuclear power generation. However, because of the geographic environment, the distribution of energy resources is widespread such as the coal fields locate in the north-east and north, and hydropower in the south-west, which results in the geographical mismatch between the location of energy resources and the fast growing industrial load centers of the east.

In 2011, China may add 80 gigawatts of power generation capacity, bringing total capacity to 1040 gigawatts. By the end of this year, the hydropower capacity may reach 220 gigawatts and nuclear power capacity may total 11.74 gigawatts, more than 14 gigawatts of wind power and 500 megawatts of solar capacity may also be added this year

As the coal resources are so rich in China, which has been proved the reserves of 4 trillion tons, and accounted for 70% of energy, the thermal power generation is always predominant in the structure of power in China. During January and June in 2011, the thermal power industry sales income amounted to 605.7739 billion yuan, year-on-year growth of 17.36%, and the profit amounted to 8.7245 billion yuan. In recent years China has successively introduced a batch of 300 MW, 500 MW 600 MW and 800 MW supercritical pressure units. Through debugging and improvement these units have been operating smoothly with higher availability and efficiency gained. It has laid a certain foundation for China to develop home-made supercritical pressure generating units. Nowadays, the important direction of the adjustment of the electric power industry in China is sustainable development, environment protection and energy saving. As a result, a lot of small thermal power units with low energy efficiency and heavy pollution have been shut down. Additionally, as rising coal prices on global markets will drive up domestic coal prices, China's thermal power plants may suffer more loss this year. However, during twelfth five-year (2011-2015), there will be 14 large coal base construction push forward in China, and the new construction scale of thermal power will reach to 260 million to 270 million kilowatt. According to the Proposal on Formulating the Twelfth Five-Year Program (2011-2015) on National Economic and Social Development which has released in October 2010, new energy and environment protection technologies are among the seven new strategic industries supported by China's central authorities.

During January and June in 2011, the nuclear power capacity in China was 41.411 billion kWh, year-on-year growth of 24.16%. On 15 December 1991, the first nuclear power reactor, a 288 MWe PWR at the Qinshan Nuclear Power Plant, was connected to the grid. At the end of 2011, there are 14 nuclear power reactors spread out over 4 separate sites and 27 under construction in China. Most nuclear power plants are located on the coast where near large cities and generally use seawater for cooling a direct once-through cycle. Thus especially after the Fukushima Daiichi nuclear disaster in Japan, China announced on 16 March 2011 that all nuclear plant approvals were being frozen, and that full of safety checks of existing reactors would be made. In fact, there must be the disaster for many years if the nuclear power plants just rush to be built without considering the safety, and China also has asked for international assistance in training more nuclear power plant inspectors. Because of the serious pollution of air quality and the global warming, the nuclear power generation has a very important positive position in China's future power development, and China has planned to build up another 30 sets of nuclear power generator within 15 years with total installed capacity of 80 GWs by 2020, accounting for about 4% of China's total installed capacity of the electric power industry.

Energy is central to sustainable development and poverty reduction efforts. It affects all aspects of development, such as social, economic and environment, including livelihoods, access to water, agricultural productivity, health, population levels, education and gender related issues. Energy use and supply is of fundamental importance to society and with the possible exception of agriculture and forestry, has made the greatest impact on the environment of any human activity. Although energy and environment concerns were originally local in character, for example, problems associated with extraction, transport or noxious emissions, they have now widened to cover regional and global issues such as acid rain and the greenhouse effect. Such problems have now become major political issues and the subject of international debate and regulation. It is for this reason that there is a need for know more about the energy and environment issues.

So far, the global effect of energy is still about the climate and the ozone layer, so the earth warming and the ozone layer protection has become an important topic of international leaders. And all sorts of other energy have different effects on the environment. Just concerned about coal, the main exhaust is carbon dioxide which is the greenhouse gas, and also with the emission of sulfur dioxide which contributes to acid rain. Meanwhile, the impurity in the ash will become harmful material after calcining and shattered, which also increased the burden of the environment. About the biomass fuel, it is of renewable energy with few metal elements, but burning in the poor oven, it will give birth to carbon monoxide, smoke and organic compounds. If the chimney smoke ability is poor or be in cold area with adverse ventilation, the concentrations of indoor harmful substance can be very high. The power efficiency of hydroelectric is much high, but it needs to build reservoir. Although build dams should be mature technology, several times of dam break and overflow water accidents also happened. If the conservation of water and soil in upstream is not good enough, the reservoir will have deposition and cannot play its benefit, and change cultivated land, forest and grassland to lake, it also should be analyzed and considered the ecological consequences. Here are just some examples, there are still many environment impact of different energy. We need energy, at the same time we should be more rational mining and utilization of energy, with the minimum impact on the environment.

To reduce global warming, acid rain and some other environment problems associated with fossil fuels, the whole world is looking for the renewable energy to replace the conventional energy, such as sunlight, wind, biomass and so on. However, all renewable energy technologies are not appropriate to all applications or locations. As with conventional energy production, there are environmental issues to be considered, and for renewable energy, the main environmental issues can be solved, but meanwhile, there will be other environmental impacts should be considered.

It is hard to imagine an energy source more benign to the environment than wind power, it produces no air or water pollution, involves no toxic or hazardous substances, and poses no threat to public safety. But the wind industry should face the serious obstacle about the visibility and noise of wind turbines, and their impacts on wilderness areas. And one of the most misunderstood aspects of wind power is its use of land. Most studies assume that wind turbines will be spaced a certain distance apart and that all of the land in between should be regarded as occupied and cannot be used any more. This leads to some quite disturbing estimate of a wide range of land area required to produce substantial quantities of wind power. However in reality, the wind turbines themselves occupy only a small fraction of the land area and the rest of the land can be used for other purposes or just left in its nature state. For example, in Europe, farmers plant right up to the base of turbine towers, and in California cows can be seen peacefully grazing in their shadow. This results in the substantial benefits to landowners. However, in other words, the wind power development also has created some serious land-use conflicts, especially near populated areas, people often regard the wind turbines as unsightly and noisy, or just fear their presence may reduce property values. Generally speaking, in appropriate areas, and with imagination, careful planning, and early contacts between the wind industry, environmental groups, and affected communities, siting and environmental problems can be surmountable.

Hydropower as a kind of renewable energy and green energy, it has been used by many countries. Especially in China, hydropower plays an important role, as China is one of the countries which has the most abundant water resources all over the world, and ranks first in the world, which almost accounts for 1/6 of the earth. And by the end of 2011, the hydropower capacity may reach 220 gigawatts. However, the potential of hydropower in China is only about 25%-30% utilized, there still remains much space for further hydro development. Additionally, the environmental impacts of hydropower cannot be slighting. Especially of the Three Gorges Dam in China which is the world's largest power station in terms of installed capacity (20,300 MW). However, the dam flooded archarological and cultural sites and displaced some 1.3 million people, and is causing significant ecological changes, including an increased risk of landslides. As of June 2008, China relocated 1.24 million residents, about 1.5% of the province's 60.3 million and Chongqing City's 31.44 million population. About 140,000 residents were relocated to other provinces. On the other hand, the 600 kilometers long reservoir flooded some 1300 archaeological sites and altered the appearance of the Three Gorges as the water lever rose over 600 feet. Cultural and historical relics are being moved to higher ground as they are discovered, but the flooding inevitably covered undiscovered relics, and some sites could not be moved because of their location, size or design. In addition, days after the first filling of the reservoir, around 80 hairline cracks were observed in the dam's structure. There are still many other effects, the forest cover, the wildlife, and even the national security. Developing hydropower is the long-term strategic policy for the economic and social development especially the sustainable development in China. It would effectively reduce the combustion of the coal, oil and natural gas resources, not only saving valuable petrochemical energy resources, but also protecting the environment.

Everything has its dual character, the renewable energy is also a rapier. Undoubtedly, with great significance, the renewable energy should be developed and utilized. It is one the important measures to protect the environment and combat climate change, it is also an important choice to develop new economic growth areas, promote economic transformation and expand employment. At present, the international oil price is soaring again and again, so the development of renewable energy has been the main concern for many countries. The significance of the renewable energy is much more than this, it will also change the idea of people. It can greatly out of resource constraints, thus reduce the conflicts for resources, and of course it can get rid of any environmental problems which are caused by the development of industry. Although there may be some other environmental impacts, it can be solved with qualified technology, effective measures and positive idea. Overall, the renewable energy will bring the new revolution not only of the way of life, but also of the ideas.

5.1.2 Environment Problems in China

Nowadays, the environmental problems are serious and important, especially the urban environmental problems. While sometimes the urban environmental problems are defined broadly, and sometimes narrow, when people complain of the environmental problems, they are referring to damage to the physical environment which is caused by other people, and with harmful consequences for human welfare. Thus the urban environmental problems are threats to present or future human well-being, resulting from human-induced damage to the physical environment, originating in or borne in urban areas. Actually, the definition of the urban environmental problems should include the localized environmental health problems such as inadequate household water, sanitation and indoor air quality; the city regional environmental problems such as ambient air pollution, inadequate waste management and pollution of rivers, lakes and coastal areas; the extra-urban impacts of urban activities such as ecological disruption and resource depletion in a city's hinterland, and emissions of acid precursors and greenhouse gases; the regional or global environmental burdens that arise from activities outside a city's boundaries, but which will affect people living in the city. As the international and local interest and capacity to address the urban environmental problems increases, there are more new locally-driven environmental strategies emerging. Many cities in Europe, America, Latin America, Asia and Africa are experimenting with city-wide initiatives to address environmental problems, and such initiatives are supported, which are often called Local Agenda 21s [23]. However, there is still much to learn from these local initiatives, including how best to define urban environmental problems in their local context.

The urbanization has been the dominant trend in the whole world. With the high pace of social and economic development and the resulting growth of city and town population, lack of infrastructure, congested traffic, environmental degradation and a housing shortage became the major issues faced by cities and towns in their sustainable development. Especially in China, it has several environmental issues that affect the Chinese environment. One of the serious negative consequences of the China's rapid industrial development has been increased pollution, smog and degradation of natural resources. Much solid waste is not disposed of, water pollution is a source of health problems across the country, and air pollution causing many premature deaths each year. China's polluted environment is largely a result of the country's rapid development and consequently a large increase in primary energy consumption.

In China, the rate of urbanization is increasing every year, more and more people move to urban area, and which results in the continued growth of the resource and energy consumption. It can be seen from the figure below:

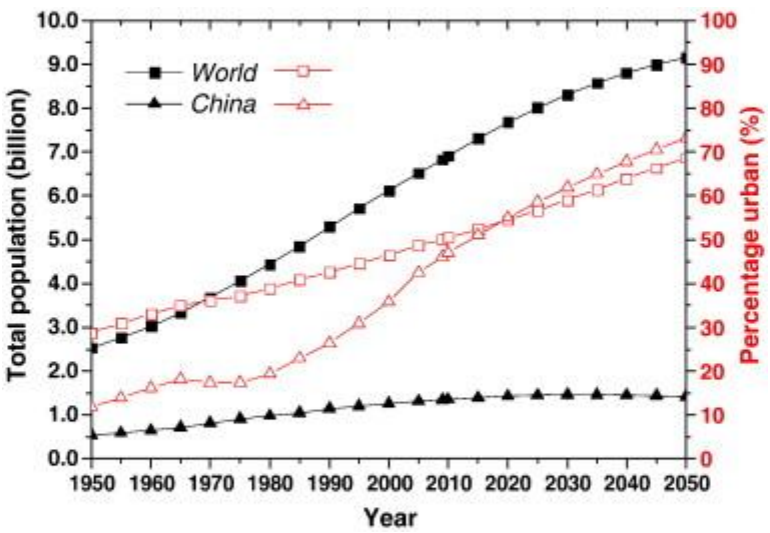

Figure 20: World urbanization prospects and rapid urbanization in China (source: United Nations)

Many traditional urban environmental problems still have not been solved, but many new problems and challenges keep appearing, and the urban environmental problems still restricts the sustainable development of the city. In the current and future period, the urban environmental problems in China are still facing several challenges. For example, there is huge pressure on the city resources and the environment with the increased urbanization and the rapid population growth, such as the shortage of city water, the continued rapidly increase of motor vehicle quantities, sewage and garbage and waster production has risen sharply, and the total amount of pollutant over the environmental capacity. As a result, to protect and improve the urban environment qualities is a very arduous task. Additionally, the construction of environment infrastructure cannot catch up the speed of urbanization, in the last 10 years, the rate of the national urban sewage treatment is less than 60%, though the nearly 80% of urban living garbage has harmless handling, many cities have shortage of processing power, and the efficiency of garbage disposal facilities is too low. In recent years, the environment improving is focus on the main cities, which results in the intensified trend of the surrounding areas and small and medium-sized cities environmental problems, and once the lack of regulation, the industrial pollution will have serious effect to the environment of the surrounding cities. On the other hand, the urban lands rapidly grow, which destroy the original ecological system, and reduce the urban environment capacity. Thus it can be seen that industrial pollution prevention, environmental management and environmental protection ability construction is the key of the future work, and the step of urban environmental infrastructure construction should be speed up.

In general, the consumption of energy is so large in China, and even the renewable energy also has the impact of the local environment. Additionally, because of the large amount of population and China is a developing country, the environmental problems are inevitable. Therefore, it’s necessary to find out a way to solve such problems. And the Passive House as a new concept in China is a good choice. It not only can save more energy, but also can protect local environment. But the multi-storied Passive House needs to be considered because of the population.

5.2 The Limitation of Passive House in China

Even though the improved model of Dunoon Passive House has met the criteria and had a good performance in three selected cities in China, there are still many problems need to take into account. There are still several limitations and problems need to be solved in practice. And to evaluate the feasibility of the Passive House in China context, such problems cannot be avoided.

5.2.1 Different Climate Zones in China

As what has mentioned in the previous chapter, the climate conditions are the first factor need to take into account before designing the Passive House. China has a vast territory, thus there are several kinds of climate in different cities. If the Passive House needs to be built in each city, it must start from studying the local climate, which is much complicated. Although the Passive House met the standard in Beijing, Shanghai and Hong Kong, because installed some shading devices to reduce overheating and it may eliminate view and impede air movement. Therefore, to build Passive House in China, the climate conditions need to be studied deeply, and then the Passive House can be designed with particular construction according to the local climate condition.

5.2.2 Special Conditions in China

China is still a developing country. Although in recent years, it is developing very fast, it's unbalanced. The rich cities such as Beijing, Shanghai which developed fast, are located at east littoral area. And in the middle and west area, the cities developed very slowly. Thus the unbalanced development leads to large gap between the rich and the poor, different ambition as well. Even though almost all of people want to live in a higher standard building, they cannot afford it. Because the expensive investment to such green buildings. It is a big barrier even in developed countries. So the extremely high-tech is not adapted in most area in China. Although the Passive House is not very high-tech, it is a new concept in China and it has some new technologies, some investors may raise the prices because its new at the first stage, which will lead to the common buyers can only envy. So the more feasible strategy is to find more suitable and cheap technologies in China.

Though the government has identified the policy of energy efficiency, it has less power to guide the building market. Meanwhile, today most of the housing development is private, the investment in residential buildings increased rapidly which can be seen as below:

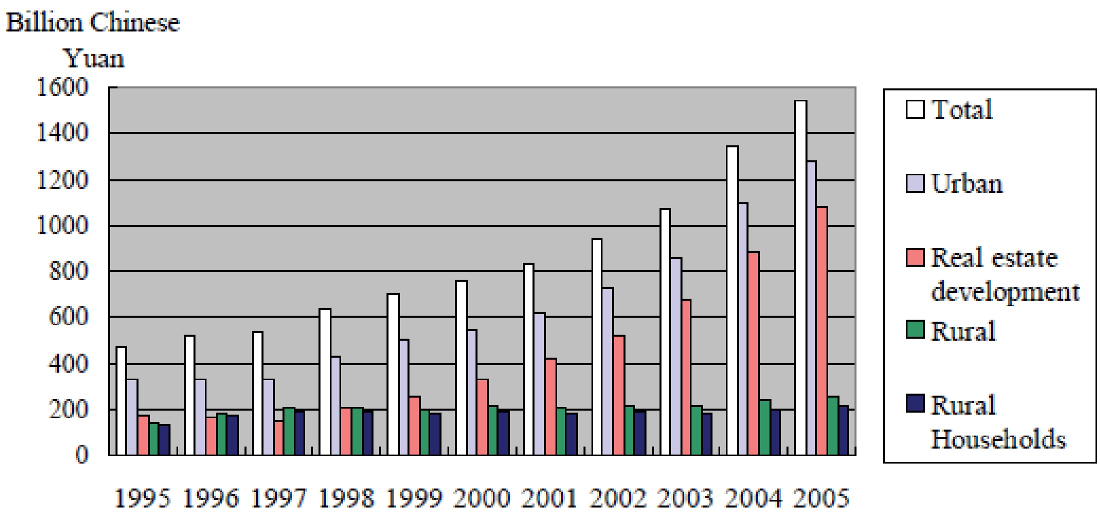

Figure 21: Annual Chinese Investment in Residential Building (source: National Bureau of Statistics of China 2006)

At first stage, the investors were just for more benefits. With the energy crisis appeared, most people began to aware of the importance of energy efficiency. However, they nearly have no experiences in such areas. And the situation of building market is much complex, as the government needs the investors to build more buildings to solve housing problems, but it will induce the environment problems and increase energy crisis. It is still necessary to study the experiences of energy efficiency from developed countries.

China is a traditional high density country. Especially in recent years, more and more people move to cities, and the cities are more crowded. With such fast urbanization, the land is short supply. Therefore, the high density communities are still be the main type in China, because small scale buildings need more are of land than large scale buildings to meet the same requirements. However, the large scale buildings will increase the environment load, investment cost, technology problems, etc, even they are positive to energy efficiency. And a large construction in a short time will create a lot of dust, that's why the air quality in China is so bad. But "time is money", a large building must be created in a short time. It is a great challenge to increase the quality and energy performance with high speed to build.

In China, the culture is different from the western countries, and the concept of people in China is also different. Chinese people would like to achieve a balance between costs and performance instead of extremely high performance at any cost. In building market, most of the investors will not develop just extreme energy efficiency buildings, because of the higher investment cost, and nearly no people willing to buy a house just because it is "green". Additionally, most people in China are not very care about if the house is green, energy efficiency. They just consider the location, comfortableness, economic benefit, etc. The concept of energy efficiency still has not been around. However, with the energy and economic crisis appeared, more and more people have been aware of such problems. Such as low carbon actions have been taken in some cities.

On the whole, China is still a developing country, some mechanisms are not very thorough, the fortune is not enough, and the concept is not interiorized. As a result, it is still a little difficult to popularize energy efficiency buildings in China, especially large scale communities. To improve such predicament still needs more time and patience.

5.2.3 Relevant Policies and Legislation in China

In the 11^{th} Five-Year Plan for National Economic and Social Development, the Chinese government has set the target to decrease energy consumption per unit of GDP by 20%. However, it's quite difficult to implement especially in the first year. To improve such situation, the central government has created a series of polices and legislation.

The Energy Conservation Law came into effect on the 1^{st} of January 1998 [24]. According to article 1, this law "*is formulated in order to promote energy conservation by all sectors of the society, increase the efficiency in the use of energy and its economic results, protect the environment, ensure national economic and social development, and meet the people's needs in everyday life*". The law was revised 2007. It said that when evaluate the performance of local government official, the fulfillment of energy conservation targets is taken into account.

The Renewable Energy Law entered into effect in January 2006 [25]. This law "*is enacted in order to promote the exploitation of renewable energy, increase energy supply, improve the energy structure, ensure energy safety, protect the environment, and attain the sustainable development of the economy and society*". It is related to the building sector only as far as solar energy and heat pumps are concerned. Additionally, a Renewable Energy Development Fund by the Ministry of Finance (MoF) is created as an important follow-up measure of the law, and it took place in June 2006 [26]. The fund provides finical means to house owners to support the installation of renewable energy appliances.

The other several standards and laws are listed below:

- Thermal Design Code for Civil Building, GB 50176-93. Date of put into effect: July 1, 1993;

- Energy Conservation Design Standard for New Heating Residential Buildings, JGJ 26-95. Date of put into effect: July 1, 1996;
- Technical Code for Renovation of Existing Heating Residential Buildings, JGJ 129-2000. Date of put into effect: January 1, 2001;
- Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone, JGJ 134-2001. Date of put into effect: October 1, 2001;
- Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Warm Winter Zone, JGJ 75-2003. Date of put into effect: October 1, 2003;
- Code for Design of Heating Ventilation and Air Conditioning, GB 50019-2003. Date of put into effect: April 1, 2004;
- National Building Energy Design Standard for Public Buildings, GB50189-2005. Date of put into effect: July 1, 2005;
- Technical code for solar water heating system of civil buildings, GB 50364-2005. Date of put into effect: January 1, 2006;
- Energy Conservation Law. Date of put into effect: January 1, 1998;
- The Renewable Energy Law. Date of put into effect: January 1, 2006.

(GB – National Standard, JGJ – Industrial Standard)

5.2.4 More Technical Problems in China

The Passive House technologies are from developed countries, and it has been developed for several years in Europe. Although the Dunoon Passive House has been improved and had a good performance in China, in practice there are still many problems should be faced.

As mentioned before, if Passive House built in China, it will be large scale construction. Thus more heat insulation material need to be installed to get the thermal performance, which is difficult to increase the production capacity of material in a short time. Although the performance of heat insulation is good, the thermal bridge will be another outstanding problem.

Ventilation systems of the Passive House have conflict with the kitchen and cooking in China. The cooking in China need strong fire which will produce a lot of smoke. Thus the ventilation systems should be stronger than the normal Passive House to meet the demand of kitchen, but there will be more energy loss. The ventilation systems need to be improved further.

The central cooling and heating systems are good choices in the Passive House. But in a large scale construction it is difficult to install individual systems in each unite. And to charge the same heating fee from each family is difficult to be accepted in China especially for the low income class.

5.3 Summary

In a summary, the Passive House can solve environmental problems and the energy crisis in China according to the situation of environmental and energy problems. However, because of the barrier of climate, special conditions, technical problems and so on in China, more improvement is needed not only in the technical areas, but also in the policies, culture, etc. And more strict regulations should be created to promote the energy efficient buildings in China.

6. Conclusion

The primary goal of this project is to evaluate the feasibility of Passive House in China context. The first step is to study the Dunoon Passive House, after improving the windows, MVHR, shading, summvent, etc, the Passive House in Dunoon met the criteria and had a good performance. Then the climate data in Beijing, Shanghai and Hong Kong was input into PHPP, but the final results are undesirable. The frequency of overheating is too large. Therefore, more improvement was applied to the Passive House.

In Beijing which is in the cold zone, the overheating limit temperature changed to 26℃, the air change rate was 0.18 1/h, and the roller blinds/marquees, white are applied in exterior position which results in the temporary shading reduction factor is 24%. So the verification of the Passive House in Beijing has met the criteria, with the 6% frequency of overheating. Shanghai is in the central of China in the hot summer and cold winter zone, hence the overheating limit temperature is assumed as 28℃, the air change rate improved as 0.18 1/h, the shading devices also selected the roller blinds/marquees, white in exterior position with the temporary shading reduction factor is 24%. Thus the Passive House in Shanghai has a good performance with the improved frequency of overheating just about 9%. Hong Kong is in the hot summer and warm winter zone, the overheating limit temperature also changed as 28℃, the fraction of opening during at night is increased to be 75%, thus the air change rate is changed to be 0.2 1/h. The shading devices are roller blinds/marquees, grey in exterior position with the 12% temporary shading reduction factor, and it is assumed to plant trees in the front of the east and west side windows, and the value of r_{other} is assumed as 20% which is just applied to the east and west side windows. Therefore, it has the 0 kWh/(m^2a) of specific space heat demand and 8% of frequency of overheating.

Finally, the situation of environment and energy in China was discussed, and it has showed that the Passive House is a good choice to solve such problems in China, it not only can save more energy, but also can protect local environment. But the multi-storied Passive House needs to be considered because of the population. Then the limitation of Passive House in China was talked about, such as different climate zones, special conditions in China, relevant policies and legislation and more technical problems. Thus more improvement is needed not only in the technical areas, but also in the policies, culture, etc. And more strict regulations should be created to promote the energy efficient buildings in China.

As a result, the Passive House in China is feasibility but not now. It still needs more time and patience to solve the barriers, and several years later, the Passive House may have a good prospect in China context.

7. Further Work

The project has been finished, but there are still many problems need to be solved and more details can be considered in the future. In fact, to plant trees and install shading devices are not so good especially for the multi-storied Passive House, cooling units can be considered in the south of China. The humid climate in south is also a big problem which will lead to mildew, thus the dehumidification need to be taken into account when design the Passive House in China. And the renewable energy systems can be installed in the Passive House to save more energy, such as PV panels, small scale wind turbines, and then the Passive House can be the zero carbon house. Additionally, the material of the Passive House should be studied, and the economic area can be discussed, just to find out if the Passive House affordable in China.

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Appendix I: Details of Dunoon Passive House

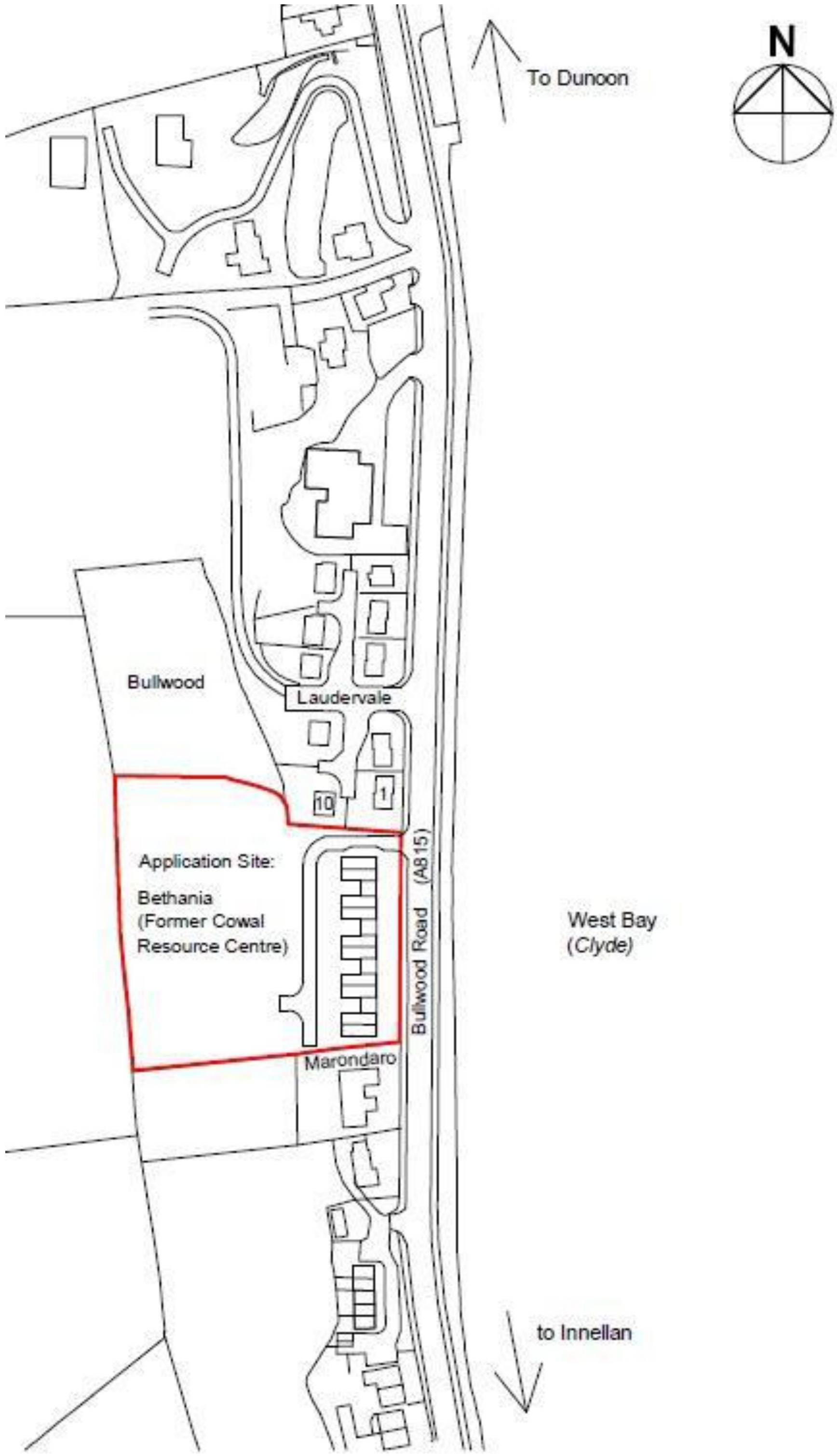

Figure 22: Location Plan of the Dunoon Passive House (source: Fyne Homes)

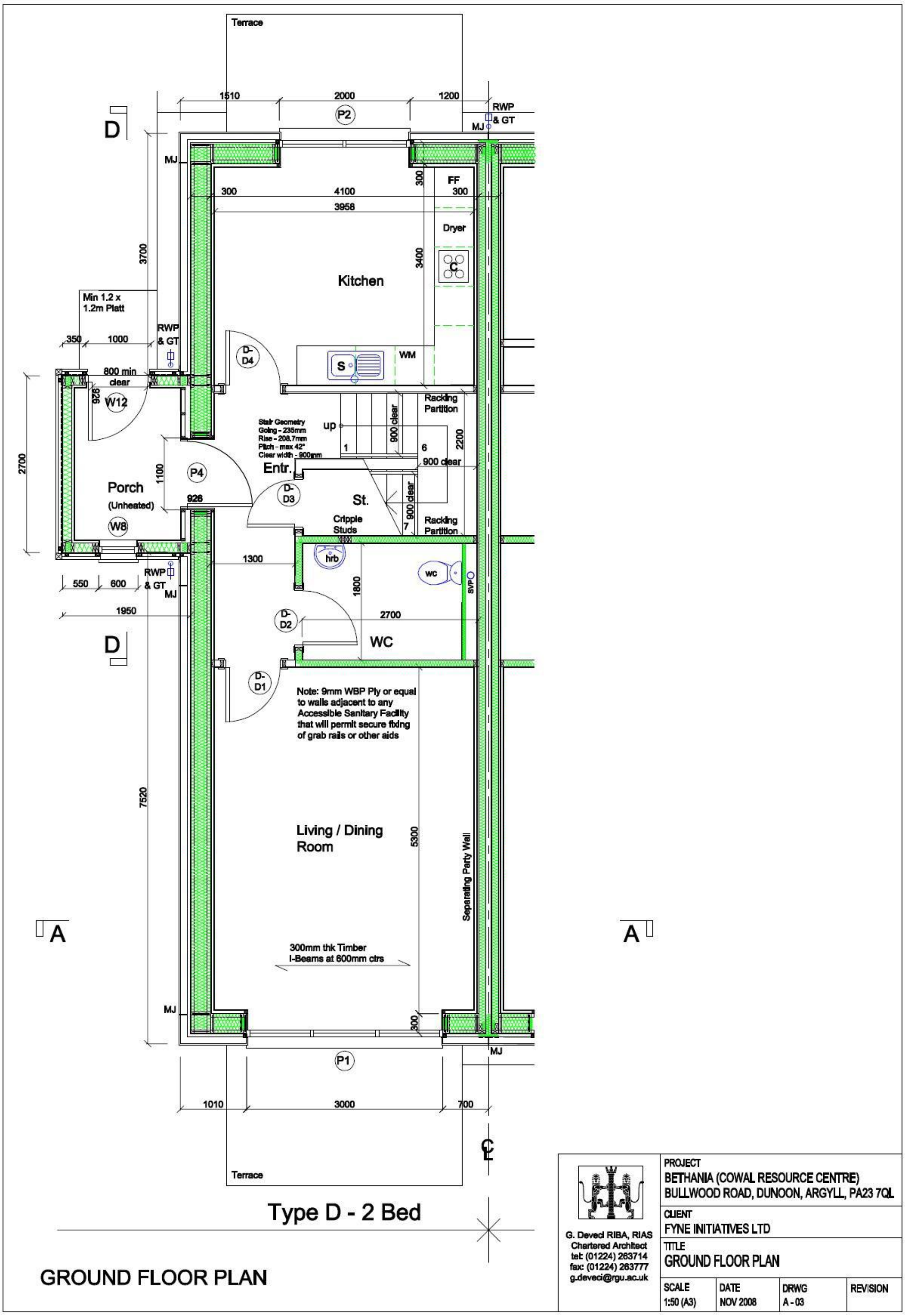

Figure 23: Ground Floor Plan of the Dunoon Passive House (source: Fyne Homes)

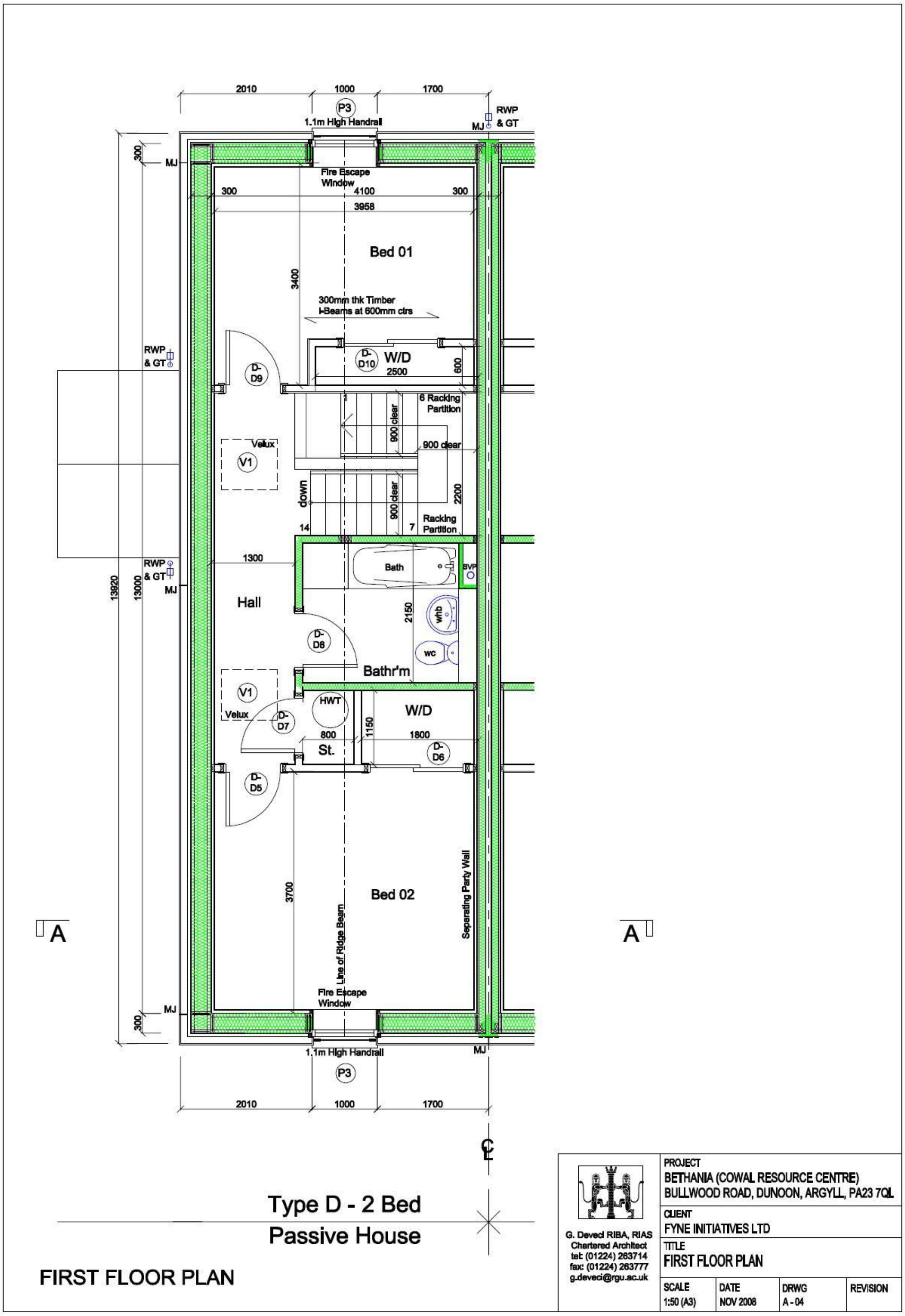

Figure 24: First Floor Plan of the Dunoon Passive House (source: Fyne Homes)

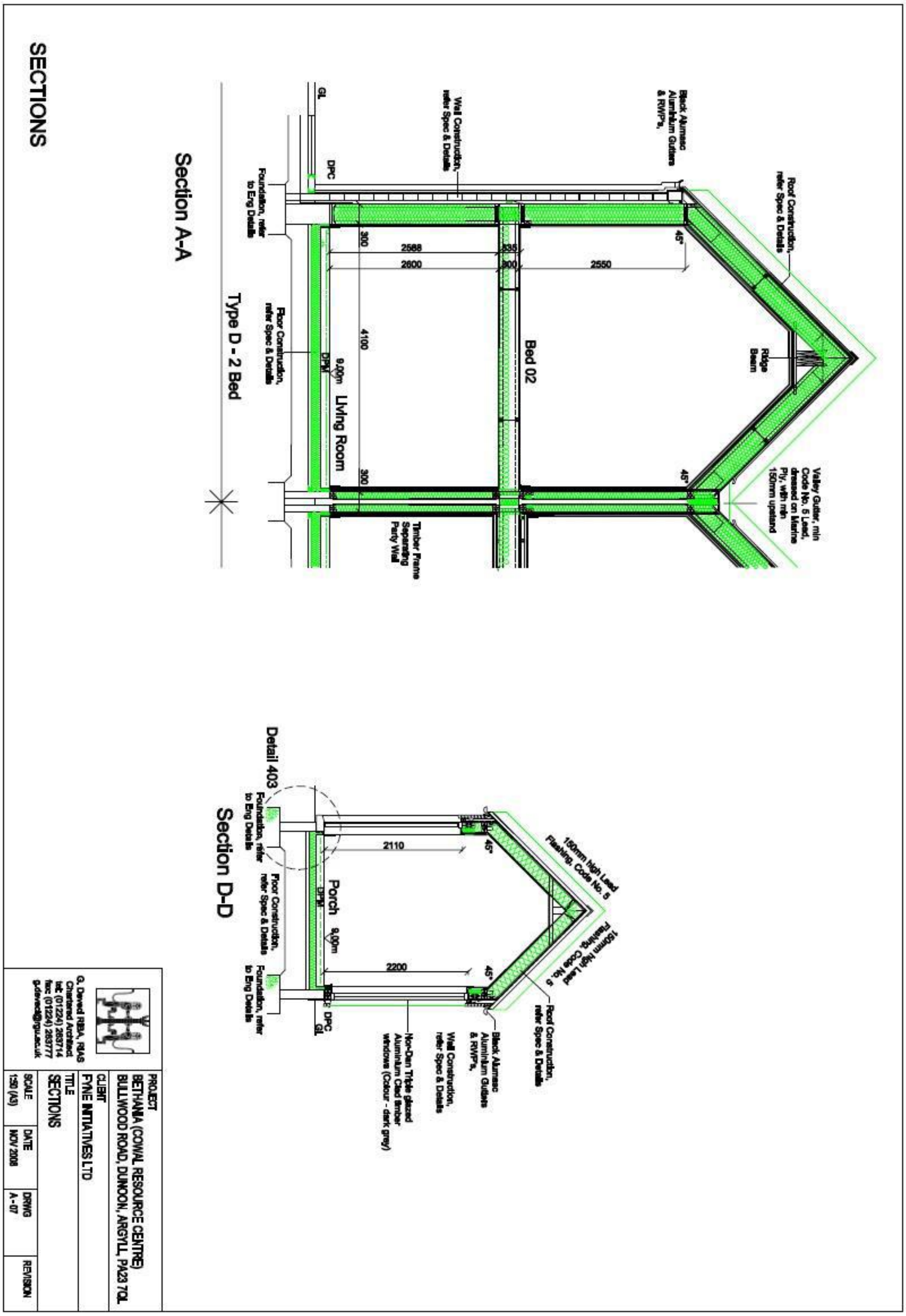

Figure 25: Sections of the Dunoon Passive House (source: Fyne Homes)

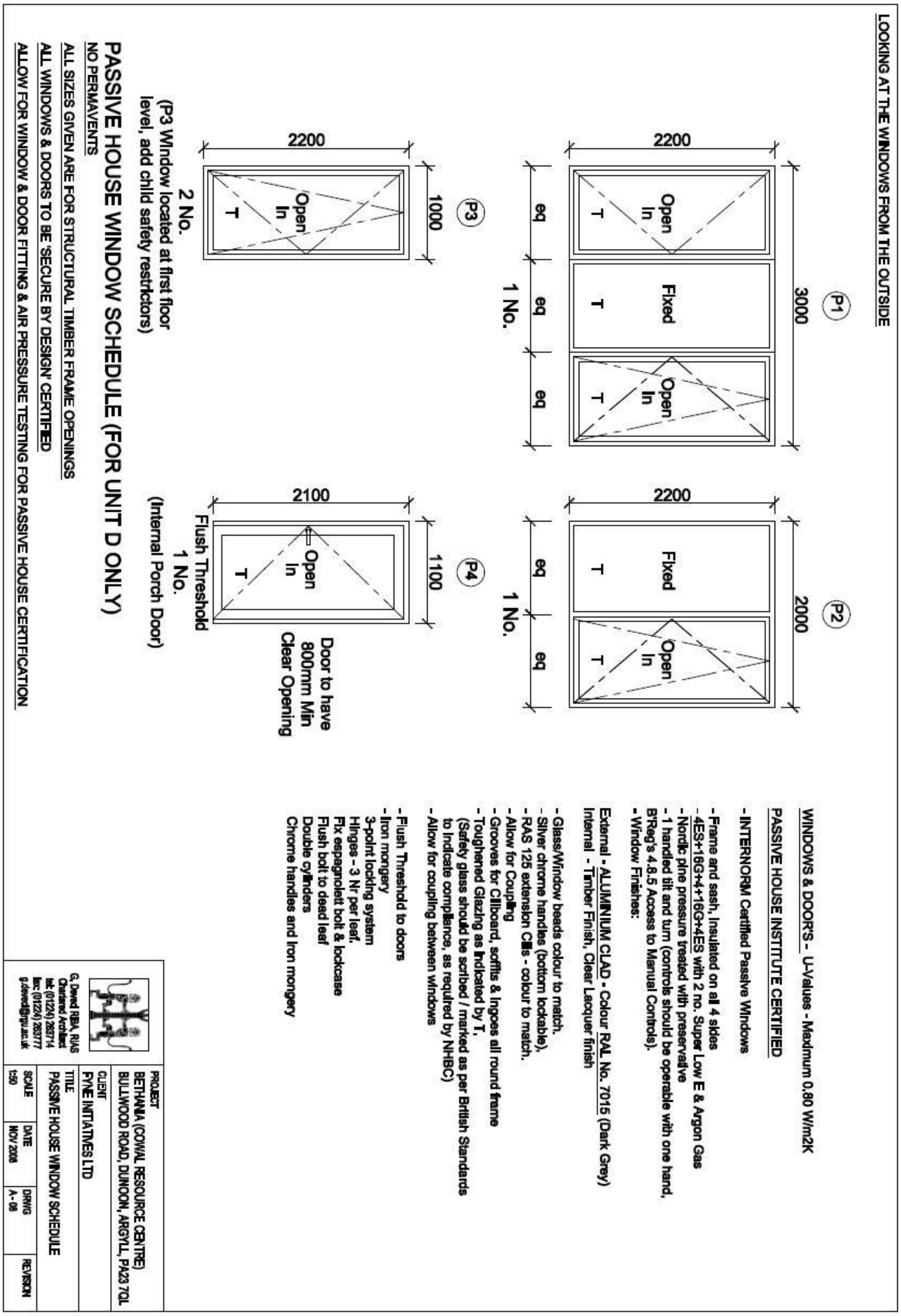

Figure 26: Window Details of the Dunoon Passive House (source: Fyne Homes)

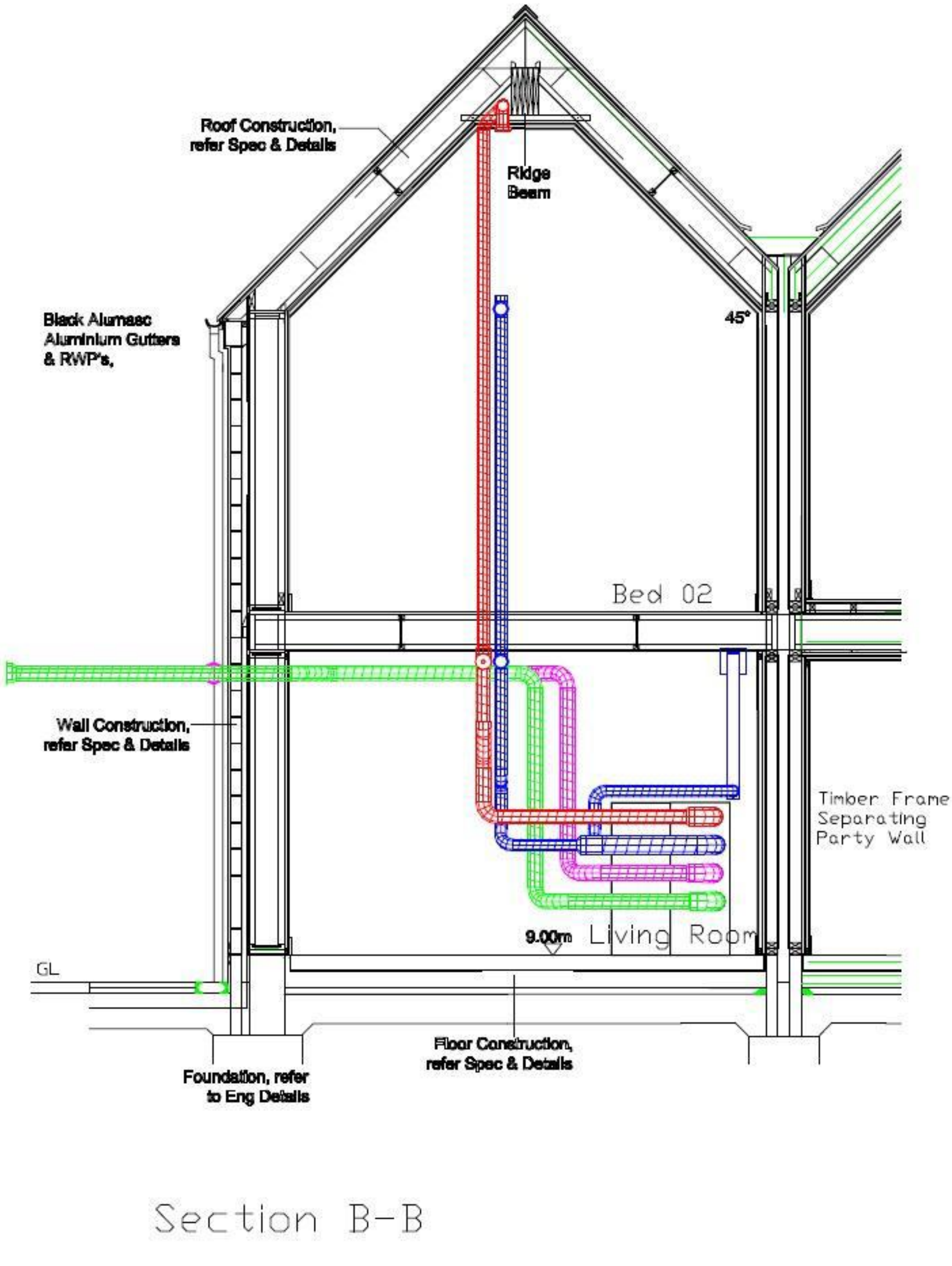

Figure 27: Ventilation Configuration of the Dunoon Passive House (source: Fyne Homes)

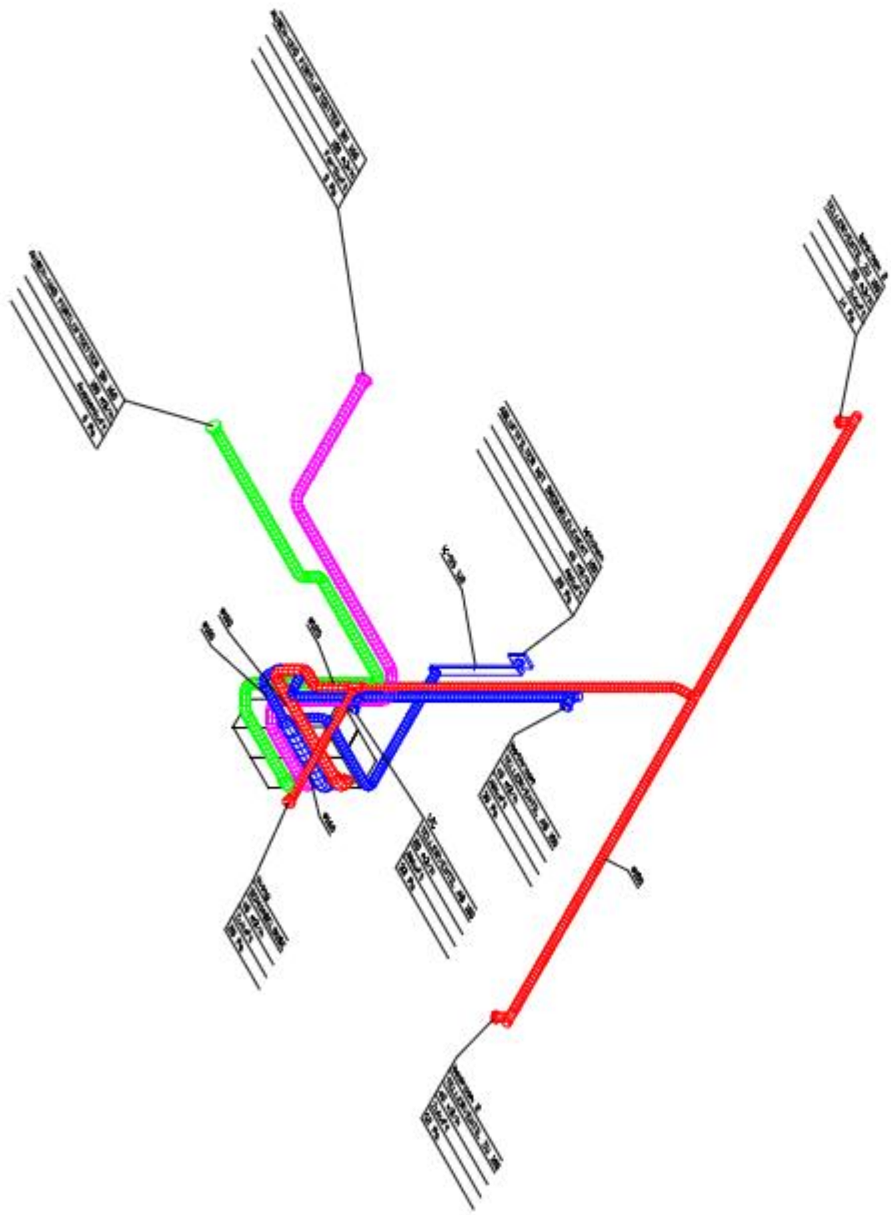

Figure 28: Ventilation Details of the Dunoon Passive House (source: Fyne Homes)

Appendix II: Technical Details of Paul Focus 200

FOCUS 200

COMPACT MECHANICAL VENTILATION HEAT RECOVERY (MVHR) UNIT
FOCUS F 200 WITH HUMITY RECOVERY
• *MADE IN GERMANY* •

WITH HUMIDITY RECOVERY

PAUL
WÄRMERÜCKGEWINNUNG

LED control unit
Listed in PEHA switch range

colored TFT touchscreen panel
within the high-grade steel framework

TECHNICAL DESCRIPTION

The PAUL MVHR unit focus 200 is used for controlled room ventilation (air flow rate: 60 to 200 m^3/h). It is equipped with a highly efficient reverse flow duct heat exchanger (European patent). Its compact design – a right or left side version of the unit is available – offers an easy installation and an optimal routing of air ducts. The MVHR unit can be used for ventilation in all living areas up to 150 m^2.
The standard heat exchanger can optionally be replaced by a membrane moisture heat exchanger, which can reclaim a high percentage of the air humidity of the extract air. The intake air is cleaned by a G4 filter or, optionally, by a F7 pollen filter. The MVHR unit is protected from contamination by a G4 filter. The housing consists of galvanized, powder-coated sheet steel. The interior lining, made of high quality polypropylene, assures a high degree of heat- and sound insulation.
The system can either be controlled by a LED control unit or a colored TFT touchscreen panel with intuitional menu navigation, which assures an ideal communication with the ventilation unit.

The MVHR unit meets the high demands of energy efficiency and comfortable installation both because of the patented PAUL heat exchanger, the constant flow fans and the intuitional colored TFT touchscreen panel.

The intelligent control management offers the following functions:

- Ventilation steps: OFF, ABSENT, STEP 1, STEP 2, STEP 3, (with TFT touchscreen panel)
- Ventilation steps: OFF, ABSENT, STEP 1 to STEP 7 (with LED control unit)
- Individual programming per ventilation step in 1% increments for intake and extract air (60–200 m^3/h)
- Weekly time programms configurable individually
- Automatic control system for external air quality sensors
- Digital communication interface for peripheral equipment
- Filter runtime control
- Frost protection for downstream hot water duct heater
- Software is configurable for shared use with fireplaces

Optional (additional module)

- Control of an exterenial defroster heating
- Control of heating circuit
- Control of electric regulating flap at GHX

focus 200

TECHNICAL DATA

Distribution by:

Dimensions: H x W x D (mm): 542 x 752 x 355

Installation:
- horizontal wall mounting
- horizontal on mounting base

Place of installation: Frost protected, preferably > 10 °C

Duct connections: 4 air ducts Ø 125 mm

Condensate: Male thread 1¼"

Material: Housing:
Galvanized steel, powder-coated
Thermal bridge free heat insulation
Heat exchanger:
- Polystyrene (standard heat exchanger)
- Salt ion membrane (moisture heat exchanger)

Weight: 25 kg

Filters: Intake air: G4 or F7 (pollen filter)
Extract air: G4

Electrical connection: 230 V, 50 Hz, ready for connection, with plug

Cable lengths:
- Mains cable (230 VAC): 2 m
- CAT-5-cable: 1,5 m
- Variable between RJ-45 wall outlet and control modules / external components, by customer

Control: Universal control

Protection: IP 40

Fans: EC radial fans with integrated electronics, V-constant control

Flow rate / Externally available pressure / Power input:

flow rate [m³/h]	externally available pressure [Pa]	power input [W]
85	44	20
83	69	24
207	104	90
103	101	34

Table 1: Selected performance data

Characteristics see Chart 1

Heat recovery rate: 90 %

Application limits: Can be used between -20 °C to 40 °C

Frost protection:
- Frost protection control or
- Defroster heater (optional) or
- Ground heat exchanger (by customer)

Backup heating:
- Hot water backup duct heater or
- Electric duct heater
(each as external unit)

Information: Temporary technical information
Subject to change in the interest oftechnical progress.

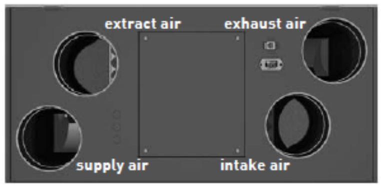

Image 1: unit version LEFT

Image 2: unit version RIGHT

Image 3: position condensate connection LEFT unit version

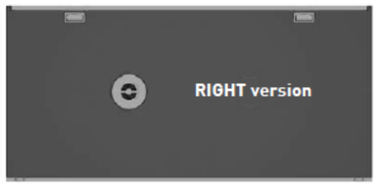

Image 4: position condensate connection RIGHT unit version

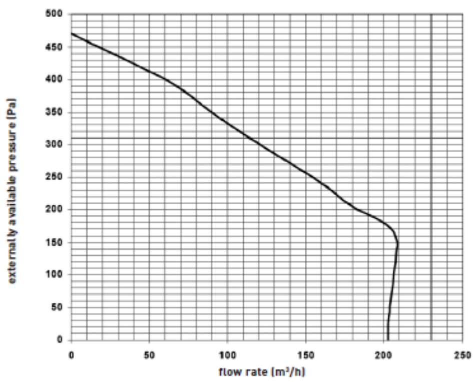

Chart 1: Characteristics for flow rate / externally available pressure

· Environment award
· Innovation awards
· European and German patents
· Product of the Year Award
· First Passiv Haus certified MVHR system
· Environment Oscar award
· INTEC award Saxony

„PAUL Ventilation Systems obtained innovation awards both on the German state and Saxon regional levels, received the German Environment Award (European-wide competition) as well as the Product of the Year and Environment Oscar awards."
PAUL heat recovery offers equipment for controlled residential ventilation with efficiencies of up to 99%, which is groundbreaking in the industry.
"New ideas in ventilation" is our vision - for fresh and healthy air in apartments with energy-saving technology for safeguarding the integrity of the environment.

PAUL WÄRMERÜCKGEWINNUNG

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