2015

RETROFITTING TIMBER FRAMES FOR BUILDING INSULATION

APPLICATION OF TIMBER FRAME PANELS WITH INSULATION OUTSIDE OR INSIDE?

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I. ABSTRACT

More than 18 million buildings in Germany are in stock, most of them, over 70%, were built after 2005. The new law aims to reduce the energy up to 50% by 2020 and for that, many of these dwellings must be adapted with any kind of insulation to comply with the new requirements. The application of timber frames with insulation is an economic method and not as damaging as other insulation chemical treated. The aim of the report is to studying the application of these timber panels with rock wool as insulation material, and check if the placement is more appropriate on the inside of the wall or on the outside. The study is based on three main topics; reduction of floor, economic and time-saving and energy efficiency, which will be analysed for both cases. For that was necessary to build two panels and test the temperature and the humidity, whose results will be exposed on graphic, tables and pictures.

Keywords: Timber frame panels, insulation, retrofitting of walls, temperature, humidity, reduction of floor, economic and time-saving and energy efficiency.

II. ACKNOWLEDGMENTS

This report was produced at Hochschule-University of Applied Science in Mainz, Germany. The study was financed by this university, with the help of the Laboratory Engineer of Department Civil Engineering, direct by Herschel, Johannes.

In addition, the thesis has been tutored by Prof. Dr. Andrew Petersen, with the help of Christian Brewer as assistant, who orders the materials and helps me with the construction of the panels.

"Deutsche Fertighaus Holding AG" is the name of the German Construction Company that was following the results of the wall tested.

The study is based on research papers, conference papers and reports which have been gathered to elaborate this thesis about the comparison between internal and external insulation in the walls of a building.

Both the search for information in English and the communication with the supervisor, the laboratory technician and the department head have been very good pleasure and how the work was employed, have led to a development of friendly and interesting report.

Finally, thanks to the people who have supported and encouraged this work, especially, my family. Without them, the chance to study abroad would not have been possible.

Mainz, 1st of July, 2015.

Pablo Tarazón Varea

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1. INTRODUCTION

This report will propose the retrofitting of Timber Frames to achieve the necessary Building Insulation.

The introduction has been obtained from the source of Energy Efficiency at European level, where all the following information has been found to focus the work to be done.

The German Federal Government hereby sends the European Commission a communication on a long-term strategy for mobilising investment in the renovation of the national stock of both public and private buildings under Article 4 of Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. *(Communication from the Government of the Federal Republic of Germany, 2014)*

This strategy starts with an overview of the national building stock, the owner and tenant structures, construction activities and the development of floor area increases and energy consumption. *(Communication from the Government of the Federal Republic of Germany, 2014)*

The residential building stock in Germany is extremely diverse and comprises a multitude of different building types and age bands with a large variety of architectural and energy performance characteristics. *(Communication from the Government of the Federal Republic of Germany, 2014)*

The official building statistics for 2011 show a stock of approx. 18.2 million residential buildings. Germany has approx. 41 million dwellings with an average living area of around 87 square metres per dwelling. *(Communication from the Government of the Federal Republic of Germany, 2014)*

Around 68 % of all dwellings are in buildings constructed before 1979. The proportion of dwellings in buildings constructed after 1995 is approx. 13 %. The building age band from the 1950s to the 1970s (less favourable from the energy and structural point of view) accounts for approx. 43 %. The majority of apartment blocks, which provide just under 20 million homes, were also built during this period. Apart from that, one and two-family houses (including semi-detached and terraced houses) dominate every age band and account for just under 18 million homes. A large part of these buildings was also built in the 1950s to 1970s. *(Communication from the Government of the Federal Republic of Germany, 2014)*

The stock of non-residential buildings is much more varied than the stock of residential buildings. With 22 %, office and administrative buildings make up the largest part of the non-residential building stock, followed by retail buildings (14 %), agricultural buildings (14 %) and the category of 'hotels, cafés and restaurants' (13 %) [BEI 2011].

Only rough estimates are so far available for floor areas. With respect to office and administrative buildings, which should account for the largest part of the overall floor area, studies suggest that the average useful floor area per building amounts to just over 1 700 m2 for buildings constructed in the most prolific construction years for office buildings (1977 to 2002) [BEI 2011].

Federal Government buildings and buildings of the federal states and municipalities account for approx. 20 % of the overall floor area of the non-residential building stock in Germany. Most of this stock of public buildings is made up of municipal non-residential buildings (approx. 14 % of the overall non-residential building stock), followed by the non-residential buildings of the federal states (approx. 4 %) with the remainder accounted for by Federal Government buildings [Fraunhofer ISI 2013].

On the whole, the buildings directly used by the Federal Administration account for only a small part of the overall non-residential building stock in Germany. Their proportion in relation to floor area is around the 2 % mark. Most of the overall floor area is used by military facilities (approx. 31 million m2). The Federal Government's civil establishments occupy a net floor area of around 8.5 million m2. *(Communication from the Government of the Federal Republic of Germany, 2014)*

With regard to its own buildings the Federal Government made a voluntary commitment to reduce energy consumption and CO2 emissions. This commitment means that CO2 should be reduced by 50 % by 2020 compared to the year 1990. In 2008, CO2 emissions amounted to approx. 2.2m tonnes, which represents a reduction of more than 66 % in CO2 emissions compared to 1990 (6.3m tonnes) (Figure 6) [BBSR 2012].

The energy consumption in military facilities has steadily gone down since 1990. In 2008, approx. 3.7 terawatt-hours (TWh) of heat energy and 1.2 TWh of electrical energy were used. This is a reduction of more than 70 % in heat energy and approx.

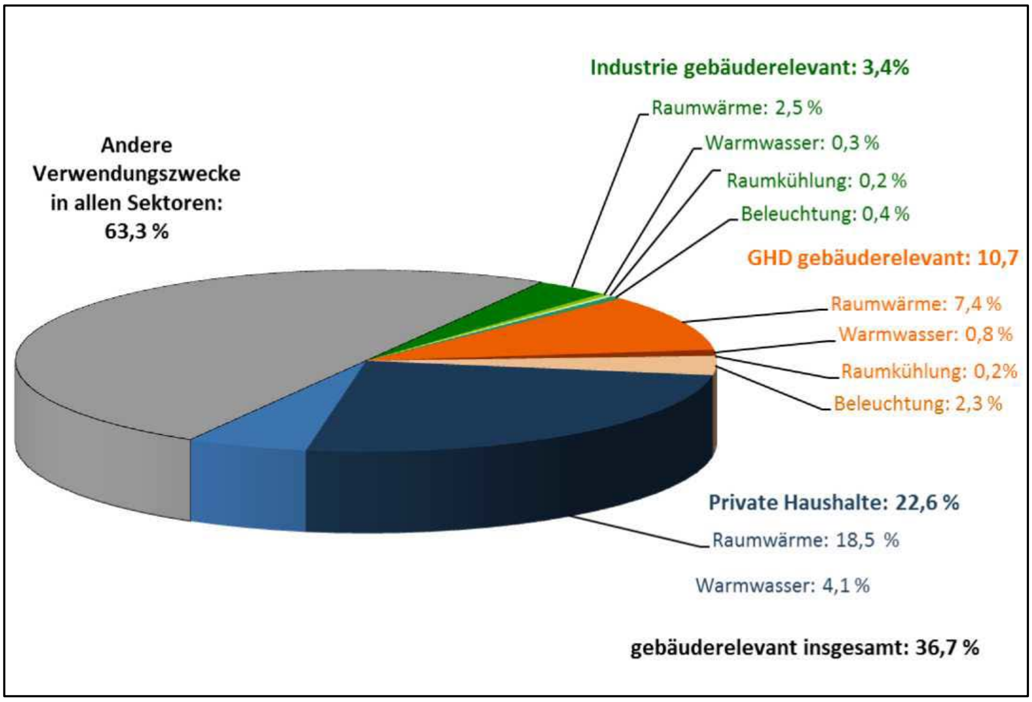
40 % in electrical energy compared to 1990. The area-specific heat energy consumption values fell by 20 % between 1998 and 2008. The area-specific electrical energy consumption however has shown a slight upwards trend since 1998 with an increase of 8 %. The main reasons for this are the increased requirements in the areas of information technology and telecommunications. An important factor influencing the overall reduction in energy consumption in the military facilities however the reduction in floor area was used [BBSR 2012].

The energy consumption in the civil facilities directly used by the Federal Administration is falling. In 2008, approx. 1.1 TWh of heat energy and 0.4 TWh of electrical energy were used. This is a reduction of more than 22 % in heat energy compared to the energy consumption in 1998. The key factor for the reduction in heat energy consumption in civil properties was the measures taken to improve energy efficiency. This can be seen clearly in the reduced area-specific heat energy consumption values. Improvements of around 30 % were achieved here. Reductions in the areas used played only a minor role. During the same period, the electrical energy consumption in civil properties went up by around 16 %. This increase was caused in particular by the growing use of information technology [BBSR 2012].

The Federal Government applies energy-saving programmes in its civil and military buildings and properties with the aim of improving energy efficiency. In the period from 2006 to 2010, a programme was introduced which made approx. EUR 120 million per year available for the renovation of buildings. The measures financed from this programme have already been implemented (60 %) or are still in the process of implementation (40 %). The measures already implemented have so far resulted in final energy savings of around 300 million kilowatt-hours [BBSR 2013].

An energy renovation roadmap for Federal Government buildings (‘central government buildings’) is currently being drawn up on behalf of the Federal Government as required under Article 5 EED. Refer to this report for further details regarding the ‘central government’ buildings. *(Communication from the Government of the Federal Republic of Germany, 2014)*

Buildings account for just under 40 % of the energy consumption in Germany. 26 % is used for heating and another 5 % for hot water. The remaining percentage is used for cooling and lighting. *(Communication from the Government of the Federal Republic of Germany, 2014)*



Picture Nº 1: Percentage for cooling and lighting. *(Communication from the Government of the Federal Republic of Germany, 2014)*

LEGEND:

- Industry building-related: 3.4 %
- Space heating: 2.5 %
- Other uses across all sectors: 63.3 %
- Hot water: 0.3 %
- Space cooling: 0.2 %
- Lighting: 0.4 %
- Commerce, Trade and Services [GHD] building-related: 10.7 %
- Space heating: 7.4 %
- Hot water: 0.8 %
- Space cooling: 0.2 %
- Lighting: 2.3 %
- Private households: 22.6 %
- Space heating: 18.5 %
- Hot water: 4.1 %

Total related to buildings: 36.7 %

Energy performance quality of external walls

The energy status of a building and measures already implemented are currently not recorded in official statistics in Germany in a differentiated manner. Current studies by the IWU on the energy performance quality of the German housing stock have found, however, that 42 % of all residential buildings have thermally insulated external walls. In just under half of these cases the thermal insulation was retrofitted in the course of other modernisation work. In approx. 76 % of all residential buildings the roof or top floor ceiling is thermally insulated and in around 37 % of the cases the basement ceiling is thermally insulated. In around 53 % (roof or top floor ceiling) or just under 26 % (basement ceiling) of these cases the thermal insulation was retrofitted. More than half of the buildings constructed in the period 1979 to 2004 have thermally insulated external walls and in more than 90 % of cases the roofs are also thermally insulated. Over 60 % of these buildings also have thermal floor slab insulation. This development since the late 1970s happened not least as a result of the introduction of the first Thermal Insulation Regulation [Wärmeschutzverordnung] in 1978. *(Communication from the Government of the Federal Republic of Germany, 2014).*

Note that the seemingly low value of 66 % of insulated external walls in new builds from 2005 onwards can be explained by the fact that only the additional insulation layers have been accounted for in the statistics. However, buildings of this age band usually either have thermal insulation or a load-bearing external wall with insulating properties (brickwork, porous concrete, etc.). It can also be assumed that buildings constructed after 2005 have external walls with insulating properties as required under the relevant version of the Energy Saving Regulation [Energiesparverordnung, EnEV] (i.e. at least EnEV 2002).

1.1 Background.

As a reference for this report, a study of dwellings in Norway has been taken into account, where a quantity of the buildings in this country in the 1970s were built with timber frames walls (Statics Norway 2009) and now these constructions need to be retrofitted to provide insulation. (TEK; Traditional Ecological Knowledge, 1997).

The application of Timber Frames as a form of insulation in buildings is very common when is performed by the inner side of the wall, but this retrofitting is complex.

Therefore, the research question is if retrofitting Timber Frames, on the outside of the facade, would provide insulation to Buildings.

1.2 Aim and objectives.

Against the background earlier outlined, this research project will be undertaken with the aim of demonstrate that external timber frames in facade, work better than internal ones. As well as, arguing that the proposal can accomplish the limits of insulation in buildings and be an advantage at the time of executing.

To achieve this aim, the following main objectives will be pursued:

Objective #1- Search the extant literature with regard to comparable studies about timber frames as internal insulation and critique this literature in order to justify the methodology adopted with the help of supporting documents.

Objective #2- Conduct laboratory tests for a period of time. For that, an insulation panel will be produced and adapted to the proof wall.

Objective #3- Collect data obtained from tests about the two options discussed.

Objective #4- Analyse data by developing comparison charts and diagrams, proving or disproving the proposal.

1.3 Scope.

The scope will be limited to buildings without any kind of internal insulation, focusing on how to adapt buildings through timber frames and insulating material, sheltered of the weather.

Around 70% of the 18 million buildings that are in stock in Germany were built before 2005, and most of them are not provided with sufficient insulation. In addition the method used to isolate was carried inside the houses, reducing the space of the rooms.

Therefore, the idea was to test around 6 days, in a time slot of eight hours each day, a wall with the same internal and external insulation (timber frames with rockwool panels) for the results to show us the correct method. The test of this wall is being made in June, and it's necessary to take into account that depending of the month of the year, the results could be different, therefore, tests may not be too significant.

Moreover, this study has set aside the investigation of what type of insulation is the most appropriate. Rock wool has been used without entering thickness and thermal performance. To make more accurate and precise research, would be necessary to make a study of the materials that are on the market and which of these have better insulating characteristics.

1.4 Motivation.

With the proposal of validating and verifying a model, the current report has been written with the purpose of getting to find out which form of insulation is more advantageous and recommended to apply to housing which must be adapted to the new rules.

Perhaps the report to develop, cannot cover a large field of business in the area of construction, but can serve to those companies specializing in the application of insulating measures as well as to the area of rehabilitation. It can be of great interest to know if the money invested is really necessary or there are other ways to provide housing insulation required, thereby leading to an economic savings for both the company and the client.

After all, the aim is to find out whether the tests carried out in other countries, in this case, Norway, in different ways and with different characteristics, could be applicable to more countries, or at least to the places that may have temperatures and humidity comparable or similar to Germany.

1.5 Chapter Summary.

More than 18 million buildings in Germany are in stock. With the new regulations for energy efficiency, the objective is to reduce the energy consumption of these up to 50% by 2020, and 20% by 2050.

2. LITERATURE REVIEW

To start developing the Chapter nº2, Literature Review, the various references are intended to organize in 3 different subchapters. The first of these, web pages with statistical information, numerical data, pricing, temperature, dimensions, etc. The second brings together techniques guides about how to build and apply the insulation in walls, catalogues of construction companies and magazines. The third and the most important group is collecting the comparable studies and the research methods in which this report is based.

Within each group, the different sources used will be developed in alphabetical order.

2.1 Web pages and data base.

Accuweather (2015). From this page, the different temperatures and humidity values of the two weeks that the insulation has been tested, have been extracted, to establish a relationship between the results and the general values outside.

Australian Scaffold (2015). In order to match the method of application of insulation for the outside and inside, it was necessary to increase the first option, the price of scaffolding for a possible placement.

Communication from the Government of the Federal Republic of Germany to the Commission of the European Union, (2014). To make sense of the story was necessary to have a goal. The introduction had to show the problem that the construction in Germany has in this moment, so this thesis may have utility in the field of this business.

Energy efficiency agreements that were accorded are in this release, as well as, energy reduction values are stated in the introduction, where we can also see the number of housing stock is in this country.

Economic Theory (2015). It is a website article setting out the main differences between the application of thermal insulation panel on the outside of the facade or inside. It is shown to have a significant relevance in the areas of space occupied and cost savings. This document has been used to justify the drawings in the model dwelling and the performance of the panel application.

FIVE database (2014). From this Spanish database, the different prices of materials and labour have been used to establish the comparison between the cost of the timber frame panel with rock wool insulation, outside and inside. Moreover, as is already written above, to the outside has added the price of scaffold.

Global Property Guide (2015). It is also necessary to understand the importance of the loss of space when the insulation is placed inside the house, to know the impact that the value of the dwelling. This one, in euros per square meter (€/m2) in Germany, provided by this source, is multiplied by the difference of floor area between the two models drawn, to achieve how much value is lost.

2.2 Techniques guides, companies catalogues and magazines.

Bre (2005). This magazine shows the construction process of timber frame buildings. Although in the past it was widely used, nowadays it is getting implemented in very developed countries. This modern method of constructing housing and other buildings uses advanced breathable membranes, insulation and vapour control layers. In the figure 8 (page 10), is shown a make-up of a typical external timber frame wall. Furthermore, several examples of such constructions are shown in the document.

Clay Brick (2011). The institute of Timber Frame Builders made a comparative between timber frame constructions and masonry ones, where thermal efficiency in the timber structures is as much as 6-8 times greater. A study in South Africa made a comparison of thermal performance between a double skin clay brick walling versus LSFB of 130m2.

Energy Efficiency in Old Buildings (N/d). Within the different points raised in this journal, the more important this report is how to understand the old buildings. The SPAB is at the forefront of research into the energy efficiency in this buildings. A hygrothermal study was carried out before and after retrofitting, where moisture content in the structure, humidity, temperature and air-tightness were measured.

This SPAB research begins to give us a clearer picture of how buildings can be retrofitted to achieve effective long-term energy efficiency through minimum intervention.

English Heritage (2012). Another magazine published in March, focuses on the insulating timber-framed walls. Mainly, the chapter that includes the most important area for our study is called “Ways of improving the thermal performance”. Here, different forms of insulate timber-framed walls are explained, but the insulation outside, between and inside the frame, has been considered, paying attention to the explanatory drawings. It is significant to note that apply the insulation on the inside can create thermal bridges.

Environmental Benefits of Building with Timber (2003). In recent times, growing pressure to design for energy efficiency has impacted on all aspects of the building industry. One possibility that begins to take force is use timber as an insulator. Along with the whole theory of how to apply this method, an example of a sustainable housing made with this material is developed.

Kingspan (2015). This renowned company of isolation, in the magazine of March of this year, made a comparison between the application of insulation by internal and external surface of the facade, naming the advantages of each method. Summary tables show the thicknesses of the insulating material to comply with U-value. Several examples of isolated houses show different forms of how to apply the insulation, depending on the type of wall and the application site.

Knauf Insulation (N/d). Another important company of the insolation business speaks in this document about three methods for insulating timber frame construction using either built-in or premium blown glass mineral wool.

- Single layer – Insulation between the studs.
- Double Layer – Insulation between the studs and Insulated dry lining.
- Twin Insulated – Insulation between the studs and external to sheathing.

This catalogue mentions these three techniques because it offers advantages to home owners, builders and contractors. From here, these points have been take into account to develop our discussion chapter.

Mosher and McGee (2013). An article of a magazine (YourHome), has focused on Insulation that acts Insulation acts as a barrier to heat flow and is essential for keeping your home warm in winter and cool in summer. A well-insulated and well-designed home provides year-round comfort, cutting cooling and heating bills by up to half. This, in turn, reduces greenhouse gas emissions.

By referring to the walls, only a small paragraph refers, *"Single skin high mass walls such as concrete block, rammed earth or mud brick can have their thermal performance significantly improved by installing insulation on the wall exterior. The simplest method is to use polystyrene board with an external render, or batts fixed between battens at around 600mm centres, covered with a waterproof cladding".* So, it has been taken into account to elaborate the rockwool insulation panels because the wall located between both, is concrete.

Retrofit Insulation in Existing Wooden Walls (2000). From this publication of the Norwegian Building Research Institute, translated by the University of Alaska, the process of the construction the insulated panel and the main idea of how the panel was going to be, have been taken. As is explained and detailed in the following chapters, the panel is made like a vertical timber structure, with the insulation between the wood studs and a vapour barrier between the panel and the wall. Being only a test to get results, our thickness is less than the minimum explained, but also the timber-framed panel is attached to a wall and it doesn't function like this.

Sustainable Energy Ireland (N/d). Ireland's national energy agency with a mission to promote and assist the development of sustainable energy, that refers to a way we can use and generate energy that is more efficient and less harmful to the environment.

This guide covers many topics, but the most important for this story is the question of the walls. As in other documents or guides, the comparison between the external insulation and the internal one, is very developed, and different issues like economics, precautions and advantages & disadvantages are mentioned. The last one has been essential to develop the sub-chapter called: Reduction of Floor.

2.3 Comparable studies and research methods.

Bichmair, Krus and Kilian. (2014). The study done by these three people talks about testing a new method for VIP (Vacuum Insulation Panels) interior insulation for heritage buildings. The interior insulation system also has been tested experimentally to assess the influence to the original surface and possible damages to the plaster. Therefore the original surface was evaluated before mounting and after removal of the VIP interior insulation. The performance of the interior insulation was measured for one heating period.

This paper highlights the concepts of reversible application of the system. Also the measured data of the interior insulation and comparison of the simulation results with the measured data are shown. A guideline to make the development of the report.

Fung and Page (2011). Branz has elaborated a report in New Zealand due to the quantity of framing is being excessive, that's why, the study examines if is possible to reduce the quantities of timber and where is the best place to do it. Precisely the dimension of the wood studs used in the panel match with those described on this paper, 100 x 50 mm.

Harrestrup, Svendsen and Papadopoulos. (2014). In order to reduce 2035 fossil fuel consumption, Denmark has started to insulate buildings for energy saving required. But challenges occur when it comes to retrofitting of heritage buildings. As having a historically listed facade, insulation must be applied on the inside and when it happens, it will become cold and condensation in the interface can occur. For the report, the importance about thermal bridges has been taken into account.

The results have shown that the percentage of energy reduced was greater than the expected one. Perhaps, the deviation might be due to altered occupant behaviour.

Johansson. (2012). This comparable study has been executed by the introduction of the use of conventional insulation materials, such as mineral wool, would demand thick insulation in the construction, around 20-30 cm. Vacuum insulation panels (VIP) is a novel thermal insulation component which can be used in buildings. With five time higher thermal resistance than e.g. mineral wool, a substantial improvement in energy performance could be reached using VIP. Meanwhile, the features and aesthetics of the building could be preserved.

This study gathers and summarizes the experiences gained during the last decade from using VIP in buildings. The study is based on reports of experiences and solutions which have been described in the literature. Research papers, conference papers and reports have been gathered to give a comprehensive basis for the conclusions.

Johansson, Et. Al. (2014). Perhaps, the studio made between Chalmers University of Technology (Sweden) and Norwegian University of Science and Technology (Norway) is the closest report to this one which is being written.

The form used is not similar, because that study hasn't used a panel for measuring moisture and temperature, beams ends inside a brick wall has been measured before and after the application of the VIP panel in the interior side of the wall. However, the test procedure of the two variables before mentioned, over a period of time, is equal to that used in the present study.

As in this study that is being done, the rains has to been taken into account because it may increase drastically the humidity. So the panel has a plastic protection (window sill) to avoid contact with water.

Krus, Theuerkorn, GroBkinsKy and Künzel. (2014). The following study conducted in Germany talks about a new material that combines insulation capacity and strength. The cattail (typha) is especially suited due the structure of the plant. The leaves have a fibre-reinforced supporting tissue filled with soft open-cell spongy tissue providing for amazing statics and an excellent insulating effect.

The functional capability of the wall construction was tested by monitoring during one and a half years testing period. For this purpose, sensors were distributed along the cross section of a selected infill area to determine temperature, relative humidity, wood moisture, and heat flow. The results were analysed by graphics and showed that the timber contained moisture due to the construction but at the end, it was reduced until very positive levels.

Maraveas, Tasiouli, Miamis and Fasoulakis (2014). The study conducted in Greece, try to isolate a traditional mansion house called “Tzotzas” which contributes to Greek heritage, without altering its architectural features. Based on Eurocode specifications, firstly, a reliable assessment of the load-carrying capacity was performed.

To this end, a finite element model was created to evaluate the static and dynamic response of the structure. More importantly, a realistic simulation of the mechanical properties was essential to minimize material uncertainties. Accurate modelling of the geometry and successful selection of various analysis and design parameters contributed to the identification of structural inadequacies in a major way. Afterwards, necessary strengthening modifications were proposed, based on non-destructive techniques.

In conjunction with the modal response spectrum analysis, time-history analyses were carried out for comparison purposes. The actual recordings used were scaled, in accordance with the Eurocode specifications, to create artificial accelerograms.

The retrofitted structure displayed better response to seismic loading and complies with the regulations.

Nyers, Tomic, Nyers. (2014). The paper analyses the technical and economic optimum thickness of a thermal insulation layer of an external wall. The observed wall was made of brick and the used thermal insulation material was polystyrene. The heat transfer through the wall takes place in the stationary regime. Unlike the panel developed in the study that is being carried out, neither the wall nor the material used are the same.

The mathematical model consisted of algebraic equations for investment, exploitation and saving. The graph-analytical method was applied to solve the mathematical model. The applied optimization criterion is the minimum payback period of the investment. By diagrams the obtained results in those formulas were expressed.

Nore, Mattson and Austigard. (2014). After many housing damages caused by water, a study was carried out comparing Cross Laminated Timber (CLT) vs. Timber Frame walls. An experiment were done, submerging 1 m2 of each type, with a complete assembly and drying in a dry environment.

The results showed different drying patterns in standard light weight timber frame walls and Cross Laminated Timber (CLT) walls. The CLT walls were not fully wetted after 48 hours, and could still absorb water from the soaked mineral wool between the CLT elements. The CLT partition walls therefore gave lower risk of mould growth, and lower actual mould growth. However, the drying period was longer compared to the timber frame wall.

The study done in Norway, elaborated graphics of two variables, temperature and humidity, collecting data over 2 months, taking as an example for this document.

Robertson, Lam and Cole. (2012). A study comparing the environmental impacts in an office made of reinforce concrete and the other one made of cross-laminated timber (CLT) was conducted for finding out which of the two behaviours was better.

The results indicated that the laminated timber building design offered a lower environmental impact in 9 of 10 assessment categories.

The categories that were measured are Global Warming Potential, Ozone Depletion, Human Health Effects, Criteria Air Pollutants, Eutrophication, Water Intake, Smog, Ecological Toxicity, Acidification and Fossil Fuel Depletion, being the last one, the only where laminated timber value were greater than concrete.

Sveipe, Et. Al. (2010). The experimental comparable study has been carried out on a test module consisting of four fields. One reference field representing a timber frame wall built according to regulations from the 1970s in Norway and three fields represent different ways of improving the thermal insulation of the reference field. During this work, a new sensor for measuring surface condensation called the wetness sensor was introduced.

The results of the experiment show that this method of retrofitting may be acceptable with respect to condensation risk in certain structures within limited climate zones, humidity classes, and building envelopes.

2.4 Chapter Summary.

The chapter "Literature Review" includes all the documents found and used for this report, with greater or lesser impact. For a better understanding, the variety of this information has been distributed into 3 groups. Web pages and Database is the first, the second called Technical Guides, Company Catalogues and Magazines and the last, based on Comparable Studies and Research Methods. A summary table has been done to understand more easily what information has been provided by each reference.

REFERENCES \ TOPIC	SPACE	ECONOMY	TEMPERATURE	MOISTURE	TIMBER FRAME	ENVIROMENTAL IMPACTS	WEATHER	OLD BUILDINGS	WALLS	PRICES	INSULATION PANELS	THERMAL INSULATION	SCAFFOLDS	ENERGY EFFICIENCY	THERMAL PERFORMANCE	NEW MATERIAL	REGULATIONS
ACCUWEATHER (2015)		X	X				X										
AUSTRALIAN SCAFFOLDS (2015)													X				
BICHMAIR, KRUS AND KILIAN (2014)			X	X	X			X						X	X		
BRE (2005)	X				X	X			X			X					
CLAY BRICK (2011)														X	X		
COMMUNICATION FROM THE GOVERNMENT OF THE FEDERAL REPUBLIC OF GERMANY TO THE COMISSION OF THE EUROPEAN UNION (2014)		X												X			X
ECONOMIC THEORY (2015)		X															X
ENERGY EFFICIENCY IN OLD BUILDINGS (N/d)					X			X			X	X					
ENGLISH HERITAGE (2015)					X			X	X		X				X		
ENVIRONMENTAL BENEFITS OF BUILDING WITH TIMBER (2003)					X	X						X		X			
FIVE DATABASE (2014)										X							
FUNG AND PAGE (2011)	X	X	X	X	X				X								
GLOBAL PROPERTY GUIDE (2015)		X								X							
HARRESTRUP , SVENDSEN AND PAPADOPOULOS (2014)			X	X	X			X	X					X			
JOHANSSON (2012)		X	X			X					X	X					
JOHANSSON, ET. AL.(2014)	X		X	X	X				X					X			
KINGSPAN (2015)			X	X					X		X			X			
KNAUF INSULATION (N/d)	X				X				X		X	X					
KRUS, THEUERKORN, GROBKINSKY AND KÜNZEL (2014)			X	X	X				X			X				X	
MARAVEAS, TASIOULI, MIAMIS AND FASOULAKIS (2014)					X			X	X								
MOSHER AND McGEE (2013)						X		X	X			X		X			
NORE, MATTSON AND AUSTIGARD (2014)			X	X	X				X		X						
NYERS, TOMIC, NYERS (2014)		X	X	X										X	X		
RETROFIT INSULATION IN EXISTING WOODEN WALLS (2000)					X			X	X			X			X		
ROBERTSON, LAM AND COLE (2012)					X	X								X			
SUSTAINABLE ENERGY IRELAND (N/d)	X								X		X						
SUSTAINABLE ENERGY IRELAND (N/d)	X					X								X			
SVEIPE, ET.AL (2010)			X	X	X				X		X			X			

Table Nº1: Relation between Literature Review and Topic. *(The Author, 2015)*

3. METHODOLOGY

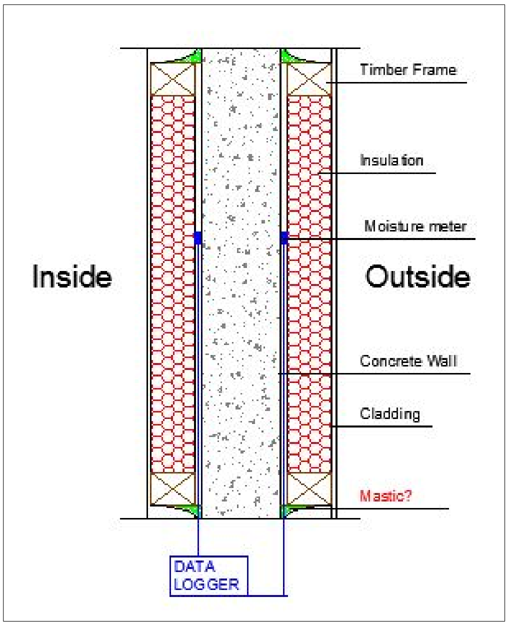
3.1 Energy efficiency.

The proposed research methodology that will be adapted from *"Retrofit Insulation in Existing Wooden Walls"* (Alaska Building Research Series, 2000), where the strategy surveyed is the use of timber-framed with mineral wool as insulation, on the external face of timber walls, being able to adapt this to any other type of wall, as we will see in the laboratory.

The comparable study has been analysed from *Application of Vacuum Insulation Panels in Retrofitting of Timber Frame Walls – An Experimental Investigation.* (Sveipe, Et. Al., 2010), and shows the results of tests conducted with the insulation on the inside wall.

The resources required will be those necessary to find out if the investigated method complies with the thermal insulation levels. Carrying out the necessary tests to achieve the results that determine whether the solution adopted for the outside insulation, meets the minimum requirements.

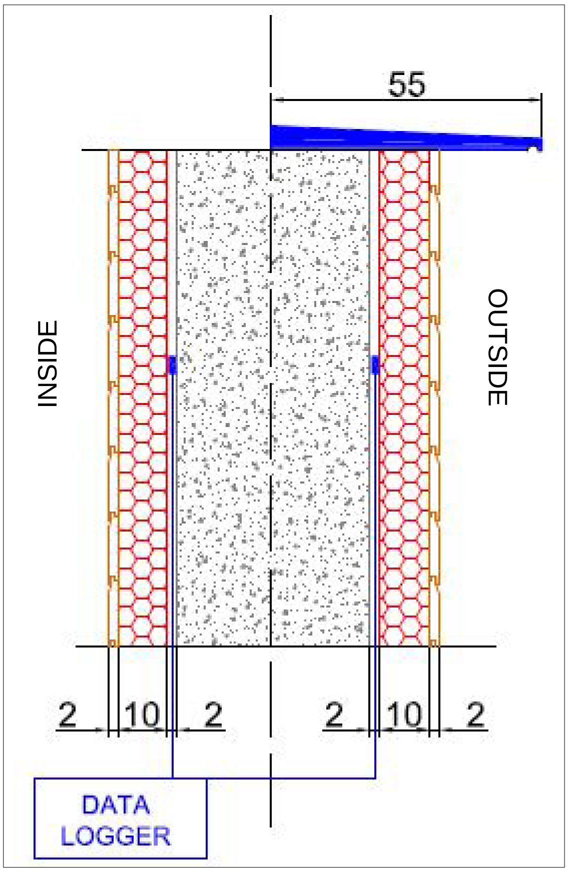
These two documents are used as a guide for a model with wall insulation, as will explained below in a drawing, to validate and verify it. This one is just a sketch to understand the process followed before getting the parameters.



Picture Nº 2: First sketch panel of timber frame with insulation. *(The Author, 2015)*

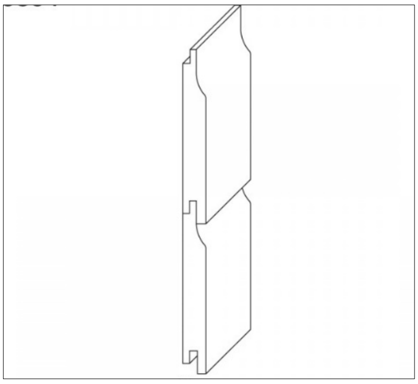
This was the first idea used to build and attach to a wall, subsequently modified following a decision by the tutor and laboratory technicians, the time to get a more easy and quick construction.

Finally built wall was formed with timber frame and rockwool as insulation panel, and as cladding material, Western Red Cedar Shiplap. To protect from the rain a plastic sill will be used.



Picture Nº 3: Final sketch panel of timber frame with rockwool. *(The Author, 2015)*

Picture Nº 4: Plastic sill. *(Google pictures, 2015)*



Picture Nº 5: Timber shiplap. *(The Author, 2015)*

Once designed and built the panel, it will be applied to a concrete wall located at the university, close to the laboratory where the data loggers will be connected to a computer. A specific program will give us the results of temperature and humidity tested. At the beginning, the idea was to do it during a period of 6 days, where due to the great price of the data logger, each day will measure about 8 hours, being 3 different slot of time.

During the construction of the panels, a problem has occurred. The thickness of the insulation material, rockwool, is 60 mm greater than wooden frames, excelling this on the opposite side in the precast timber cladding. A plastic vapour barrier foil has been used and saddle to the framework to serve as a barrier between the vapour layer and the insulating, serving also for protection.

Picture Nº 6: Insulating material added to the timber frame. *(The Author, 2015)*

It has not been possible to test the two variables previously mentioned because the panels haven't been retrofitted yet, but an expected data will be represented in graphs to understand the purpose of the study.

The panels will be attached to the wall located in the back entrance of the university, on the street Holzstraße. The wall wherein the door is located will contain the two panels. One above the other. At the top, the panel that will be on the outside, and at the bottom, the inside panel will be placed. In this way the cable may be connected, through a window, to the computer.

As will be discussed later, there are many influential parameters on the results to be obtained, and that will make these unreliable, but it will be a first analysis.

From these results, four graphics will be drawn up in, one for each parameter (temperature and moisture) and for each of the two built panels (inside and outside).

These will be displayed in the chapter called Data Analysis, where will be compared for reach a conclusion. This explains how it will be conducted our research on the part of energy efficiency, but it is still possible to develop as it wants to analyze the other two big points of our report.

3.2 Reduction of floor.

After finding a guide on how to insulate your home, one of the points developed about interior insulation disadvantages is the reduction of space. The proposed research methodology has been based from "*A Detailed Guide to Insulating Your Home*" (Sustainable Energy Ireland, 2015). Here, in this document, apart from preparing steps to isolate a home, the advantages and disadvantages are discussed, as well as risks and precautions to keep in mind.

For understanding the space reduction caused by the placement of the insulation inside the building, it has been decided to draw a model to analyze housing walls to the outside. With a series of economic and physical repercussions, affecting respectively the value of housing in the property market and user comfort referred to have less useful space.

The thickness of the panel has been adapted to those external walls of the house, at first drawing has been done on the outside facade, and the second, on the inside. Thus, useful areas of both drawings will be compared and measured, getting the conclusions referred to the reduction floor.

As the last step, the price per square meter in Germany will be adapted to the difference of surfaces, obtaining the different value of the home when it is insulated from the inside or outside.

3.3 Economic and Time-saving.

The proposed research methodology for this study has been adapted from "*On the external wall insulation technology and energy-saving materials" (Economic Theory 2015)* where the report focuses on the comparison between the placement of the insulation outside or inside.

This is the third and last point to be developed below, that will be the first to be discussed in the chapter Discussions of Results, and where the investigation about the cost and time used in the application process of the panel along a facade is shown.

To make an economic and temporal comparison, to find a database which establishes prices for materials and labours, as well as their yields, was necessary. Use only a single source was important for the study to have consistency.

Not only this information is necessary to compare and get some results, since many other factors are taken into account, and will be developed at the time. In a study of this type, as many variables as you can imagine can be added to make the most precise and accurate comparison.

It is true that the loss of money, or the costs that may involve the applying an insulating housing, is going to be compensated by energy savings in this, and so, in turn, economic savings.

3.4 Chapter Summary.

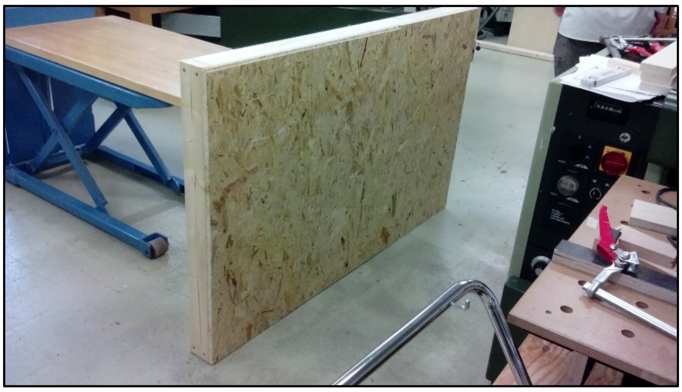
By methodology is understood, the chapter that explains the form used for the study of each item described. In this case, a brief explanation for the 3 important topics developed, has been performed. Both the topic of energy efficiency, the reduction of floor and economic and time-saving, has been described how the investigation was conducted to get the results of each subchapter. In order to obtain the results of temperature and moisture was necessary the construction of two timber frame panels with rock wool as insulation material.

4. DATA COLLECTION AND ANALYSIS

In contrast to the other two major points discussed in the previous chapter and which will be developed after, for getting information about the energy efficiency, two timber frame panels with insulation (rockwool) have been constructed. Of the same dimensions and material characteristics, one of them has been applied on the inside of the concrete wall, and the second one, on the outside.

As has been mentioned earlier, a cable with a temperature and humidity meter, located in the vapour layer on each side of the wall, will transmit data to the computer situated in the laboratory.

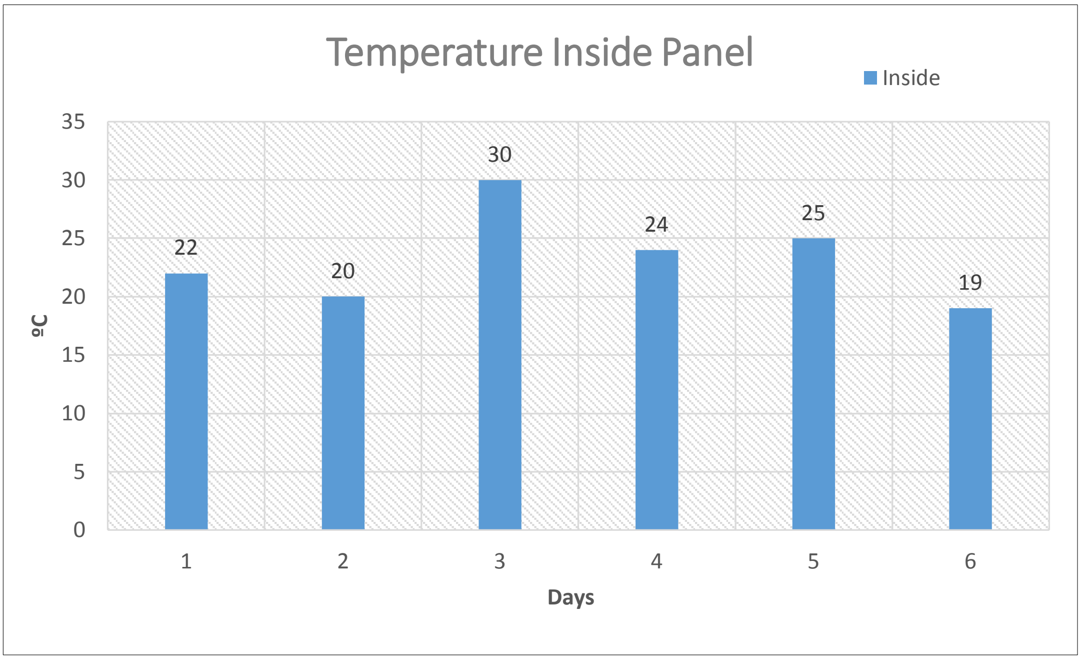
Picture Nº 7: Materials for the panel. *(The Author, 2015)*



Picture Nº 8: Panels construction. *(The Author, 2015)*

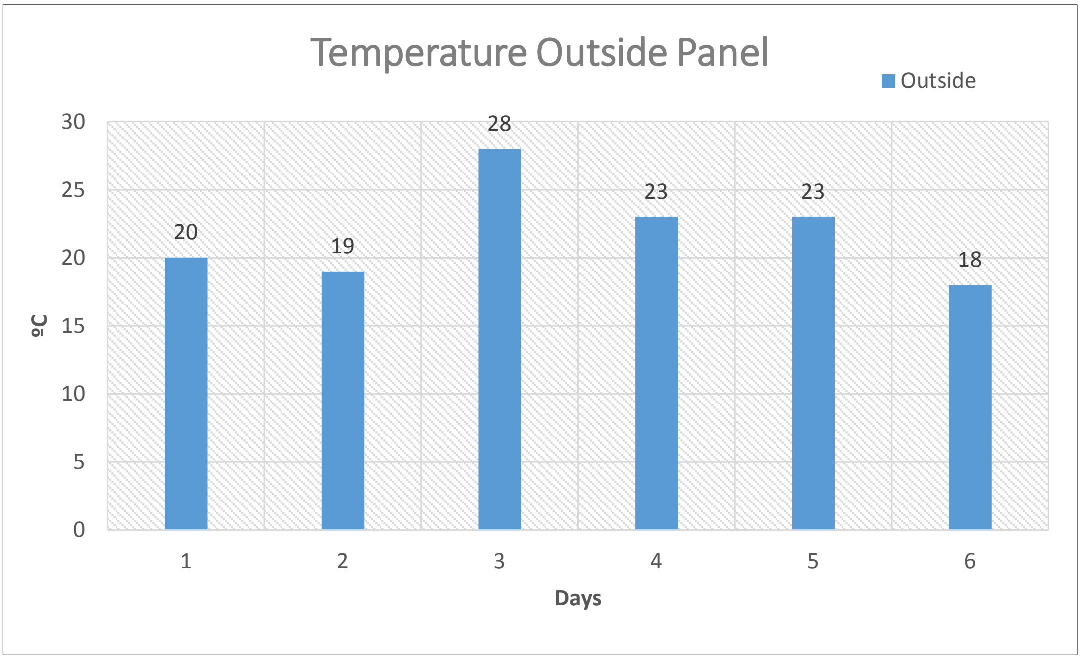
After the elaboration of the panel in the carpentry, finally, is necessary to add the panel to the wall, connecting the cable to the computer to start testing the temperature and humidity. The intended idea was to test during 6 days the panels. A data logger has been connected to a computer to get the results of these two variables. These results are shown below:

- <u>Temperature measured in the Insulation Panel (Inside)</u>



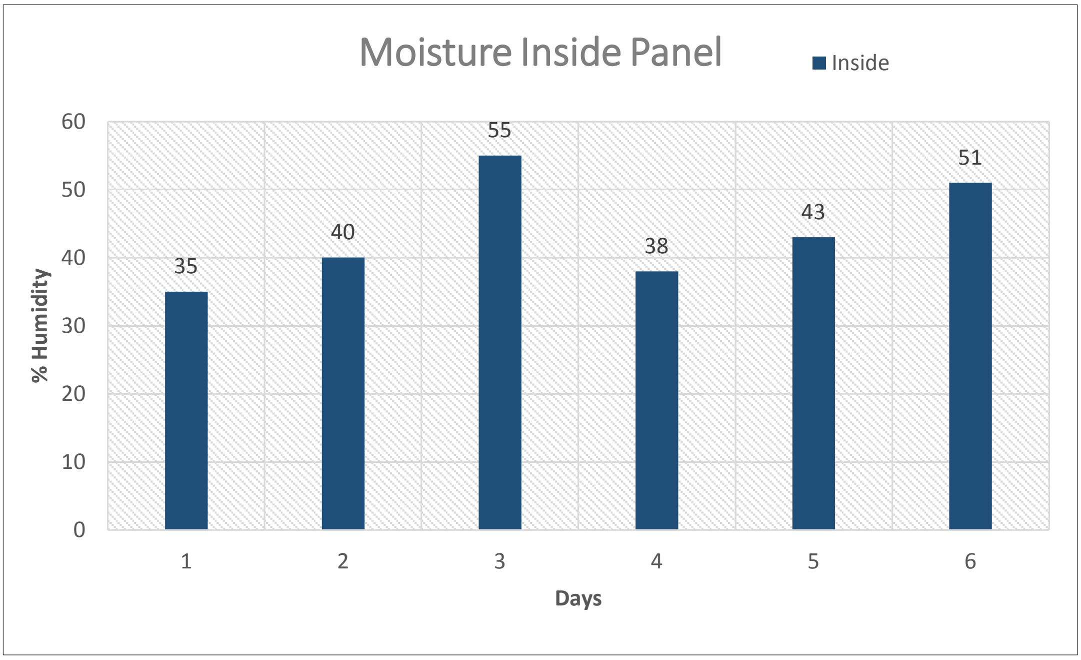
Graphic Nº 1: Temperature Internal Vapour Layer. *(The Author, 2015)*

- <u>Temperature measured in the Insulation panel (Outside)</u>



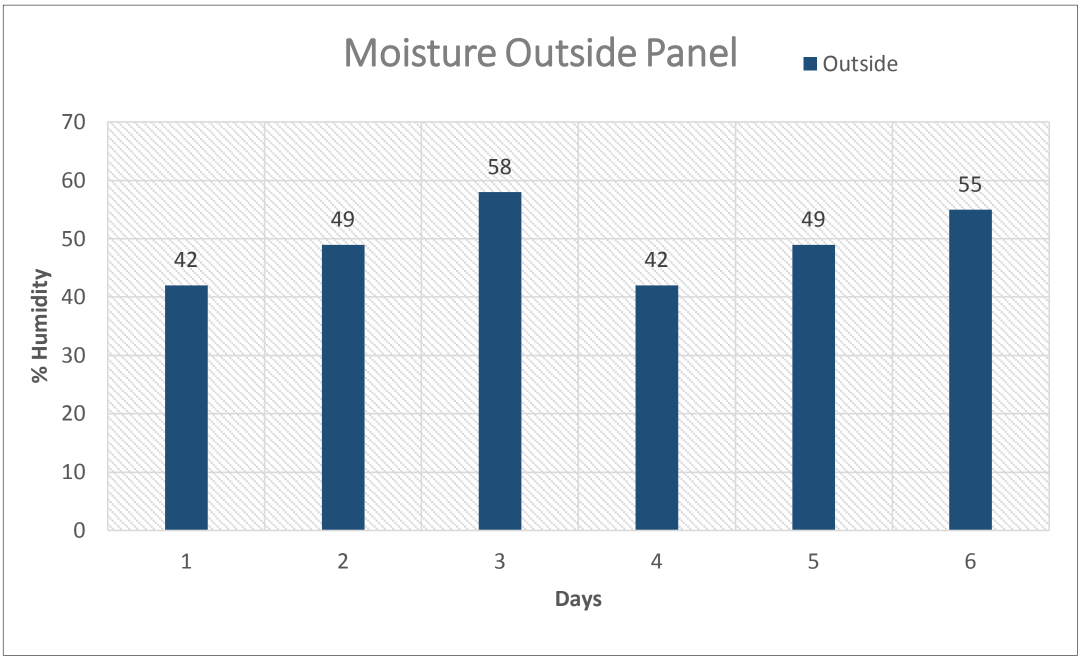
Graphic Nº 2: Temperature External Vapour Layer. *(The Author, 2015)*

- Moisture measured in the Insulation Panel (Inside)



Graphic Nº 3: Moisture Internal Vapour Layer. *(The Author, 2015)*

- Moisture measured in the Insulation Panel (Outside)



Graphic Nº 4: Moisture External Vapour Layer. *(The Author, 2015)*

With these results, two comparative tables must be made to understand the differences found between the expected data on the inside and the outside. The results should analyze for days, as are expressed in graphics, and understanding in the time set, the information obtained depends largely on the outside temperature in those days.

From various sources regarding the weather, the results have been expected like this graphic, when the information was obtained, will be extracted. This weather data will be represented by tables.

4.1 Chapter Summary.

The summary of Chapter 4 discusses through the use of graphic, the representation of the results that should be obtained from the temperature and humidity test. Four graphs show the expected results both the outside and the inside panel. Only the data is collected, so that can be analysed later.

5. DISCUSSION OF RESULTS

Mainly, the study focuses on three main topics that will be developed below.

The most important of all and main objective of this report is related to energy efficiency, (4.3).

The other two are the reduction of space inside the house when you place the insulation (4.2), and the economic and time-saving placement of the insulation on the outer face of the wall (4.1).

To do this research a timber frame panel with Rockwool insulation, whose dimensions are 1m high and 1.60m width, has been built and retrofitted to a wall placed at Hochschule Mainz.

The details of this construction will be shown when the section 4.2, reduction of space, is developed.

5.1 Economic and time-saving.

The first of the three big topics are going to be developed below, correspond to economic and time-saving in the retrofitting of the insulation in a stock building due to the new law of European Commission that says the energy employee in a dwelling has to be reduced a percentage aforementioned, before 2020. *(Communication from the Government of the Federal Republic of Germany, 2014)*

For that, is important to know the performance of the official and labourer operative that changes the final price of the m2 of rockwool panel. *(FIVE database 2014).*

The different materials needed to build the panel has been developed in the following tables (1 and 2), with their prices, that will be the same for both outside and inside use. It's understood that for a new building, the application of the insulation during the construction of it, is equal if it's done by the internal face or the external one, but, when the building is built, the movement and the stockpile of materials, is more difficult using the stairs or a lift (if there is) than using external forms like a hoist or a pulley.

In this tables, is shown the quantity of each material for 1m2 of timber frame panel and the price of that. For both the labourer and the official the performance is 1.5 hours they need to apply this square meter.

On the other hand, must be considered the price of rent a scaffolding because it is necessary to workers for the putting in place of the insulation.

m2 rockwool MW 0.035 e 100 mm outside					**74.95 €**
Exterior insulation with vapour area, Rockwool panel of 100 mm of thickness as insulation between timber frames, thermal conductivity 0.035 W/mk.					
CODE	QUANTITY	U	DESCRIPTION	PRICE	IMP
1	1.500	h	Official operative	20	30
2	1.500	h	Labourer operative	18	27
3	1.050	m2	MW 0.035 W/mk, t=100 mm	11	11,55
4	0.011	m3	Timber Frame	580	6,40

Table Nº2: Cost of Outside Panel. *(The Author, 2015 by FIVE Database 2014)*

However, the quantity of hours that needs a labour gang formed by one official operative and one labourer operative, to apply the insulation in the internal façade, is 4 times the external one, increasing the price.

m2 rockwool MW 0.035 e 100 mm inside					**255.95 €**
Interior insulation with vapour area, Rockwool panel of 100 mm of thickness as insulation between timber frames, thermal conductivity 0.035 W/mk.					
CODE	QUANTITY	U	DESCRIPTION	PRICE	IMP
1	6.000	h	Official operative	20	120
2	6.000	h	Labourer operative	18	108
3	1.050	m2	MW 0.035 W/mk, t=100 mm	11	11,55
4	0.011	m3	Timber Frame	580	6,40

Table Nº3: Cost of Inside panel. *(The Author, 2015 by FIVE Database 2014)*

With a price difference more than 180 €/m2, is necessary to know how many square meters and how long is going to take the installation of the insulation in the entire wall, to calculate if is profitable rental the scaffolding or not. For that, an estimation of 100m2 has been calculated to be knowledgeable of the time spent and the total price.

ALUMINIUM SCAFFOLD HIRE RATES

Based on concrete flat surface, close to vehicle access, no site inductions, no council fees etc. Prices are ex GST and indicative only. To confirm rates please call our office. Delivery & pick up applies to Sydney Metro Only.

DECK HEIGHT	REACH HEIGHT	WIDTH	LENGTH	DAILY HIRE	WEEKLY HIRE	INSTALL & DISMANTLE.	Delivery & Pick.
2.0M	4.0M	0.8 - 1.3M	2.0 - 2.5 - 3.2M	$50.00	$100.00	$360.00	$140.00
3.0M	5.0M	0.8 - 1.3M	2.0 - 2.5 - 3.2M	$75.00	$150.00	$360.00	$140.00
4.0M	6.0M	0.8 - 1.3M	2.0 - 2.5 - 3.2M	$100.00	$200.00	$360.00	$140.00
5.0M	7.0M	0.8 - 1.3M	2.0 - 2.5 - 3.2M	$125.00	$250.00	$450.00	$140.00
6.0M	8.0M	0.8 - 1.3M	2.0 - 2.5 - 3.2M	$150.00	$300.00	$540.00	$140.00
7.0M	9.0M	0.8 - 1.3M	2.0 - 2.5 - 3.2M	$175.00	$350.00	$630.00	$140.00
8.0M	10.M	0.8 - 1.3M	2.0 - 2.5 - 3.2M	$200.00	$400.00	$720.00	$140.00
9.0M	11.0M	0.8 - 1.3M	2.0 - 2.5 - 3.2M	$225.00	$450.00	$810.00	$140.00
10.0M	12.0M	0.8 - 1.3M	2.0 - 2.5 - 3.2M	$250.00	$500.00	$900.00	$140.00

Table Nº4: Cost of renting a scaffold. *(Australian Scaffold prices, 2015)*.

Estimation of 100m2

- External:

1m2 → 1.5 h | 100m2 → 150h/ 8h (1 day) = 18.75 days, 3 WEEKS.

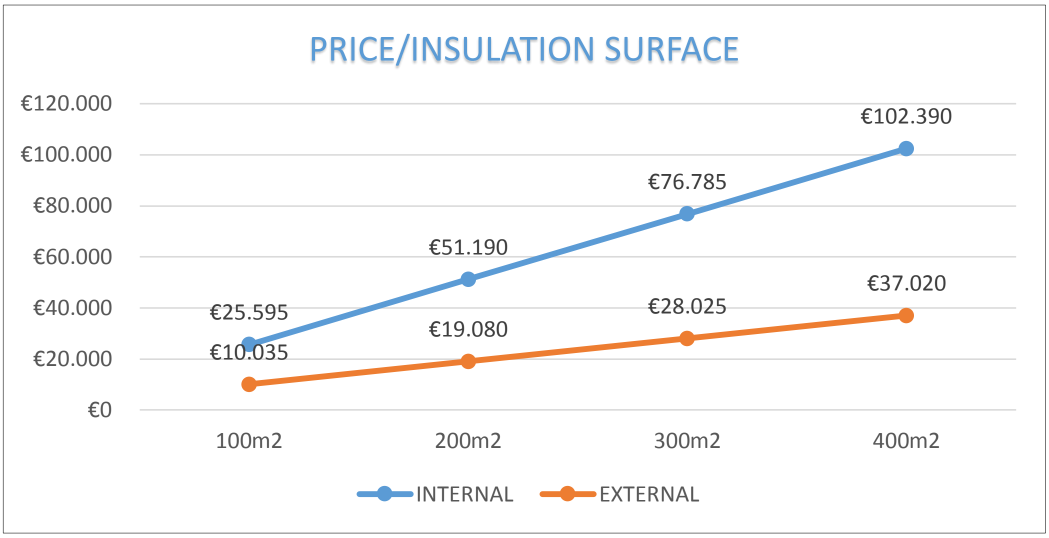
For 100m2, the price of the timber frame panel with rockwool insulation costs 7495€ plus the price of the scaffolding (900+140+3weeks*500) that is 2540€, the total cost amounts to 10035 €.

- Internal:

1m2 → 6h | 100m2 → 600h/ 8h (1 day) = 75 days, 11 WEEKS.

For 100m2, the price of the timber frame panel with rockwool insulation costs 25595€, evince that is still greater than the external option.

Also and finally, the price for double time has been calculated with the intention of knowing if a larger area is greater the price difference between the two options evaluated, and expressed in a graphic.



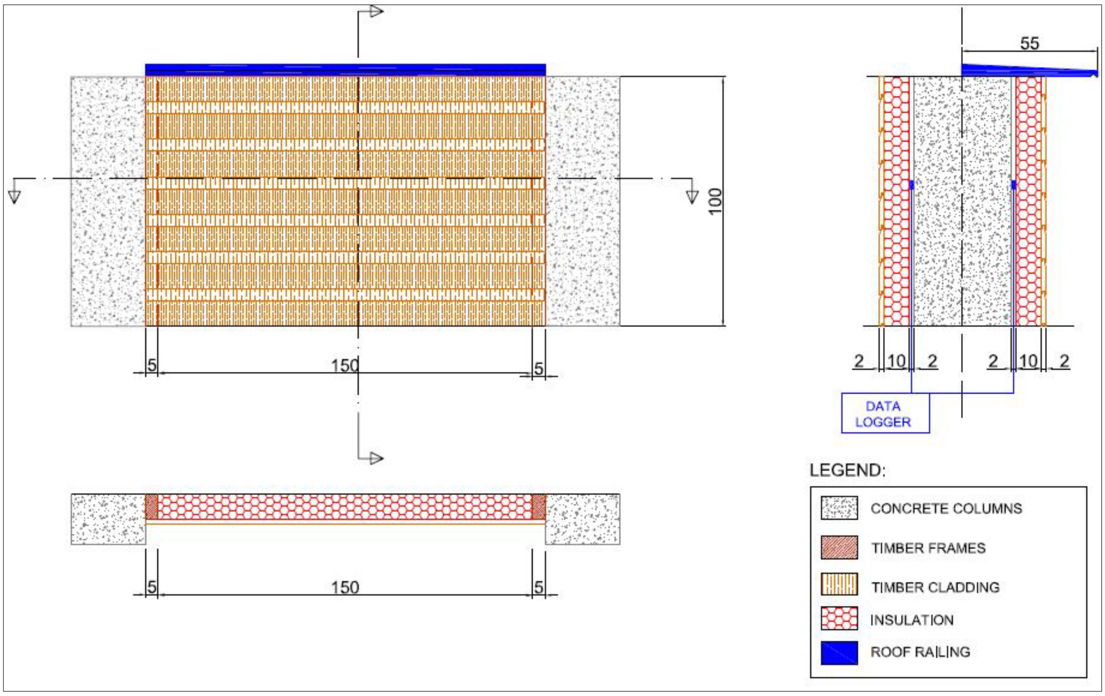
Graphic Nº 5: Estimation of prices per surface/floor area. *(The Author, 2015)*

5.2 Reduction of floor.

To demonstrate that the application of the insulation on the inside of the wall reduces the usable space of the rooms, a standard dwelling has been drawn. The house has 3 bedrooms, 2 bathrooms, 1 living room, 1 terrace, 1 hall / corridor and 1 balcony.

The insulation thickness is 10 cm and the vapour layer is 2 cm, so that for every meter of wall, 0.12 m2 of floor space would be reduced.

It has drawn 3 views needed to understand the dimensions of our panel, which will be attached to the existing wall both externally and internally

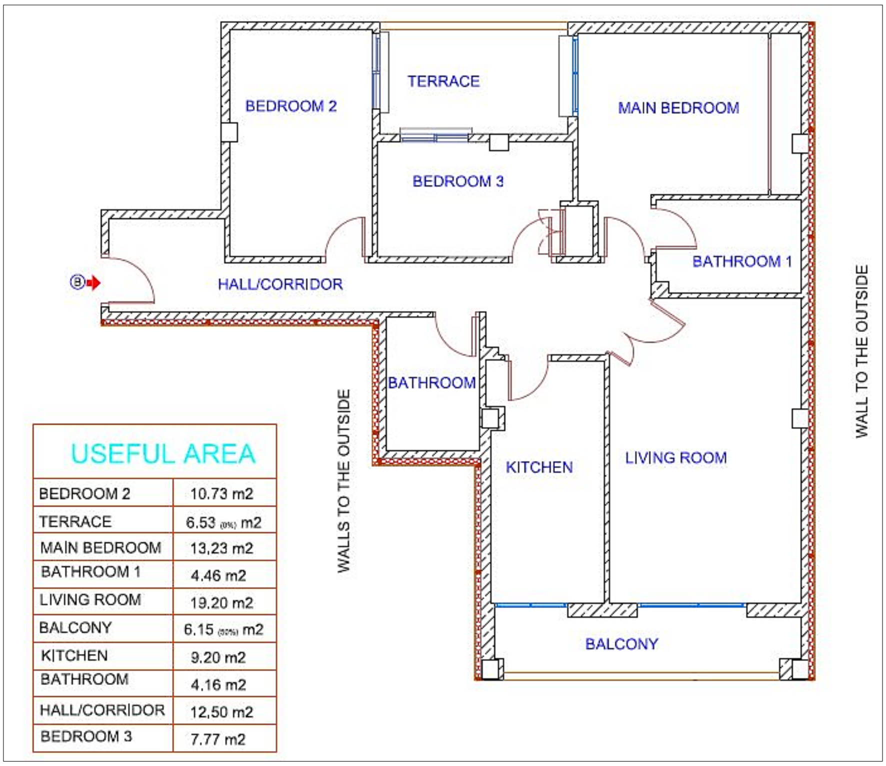


Picture Nº 9: Detail of timber frame with insulation panel. *(The Author, 2015)*

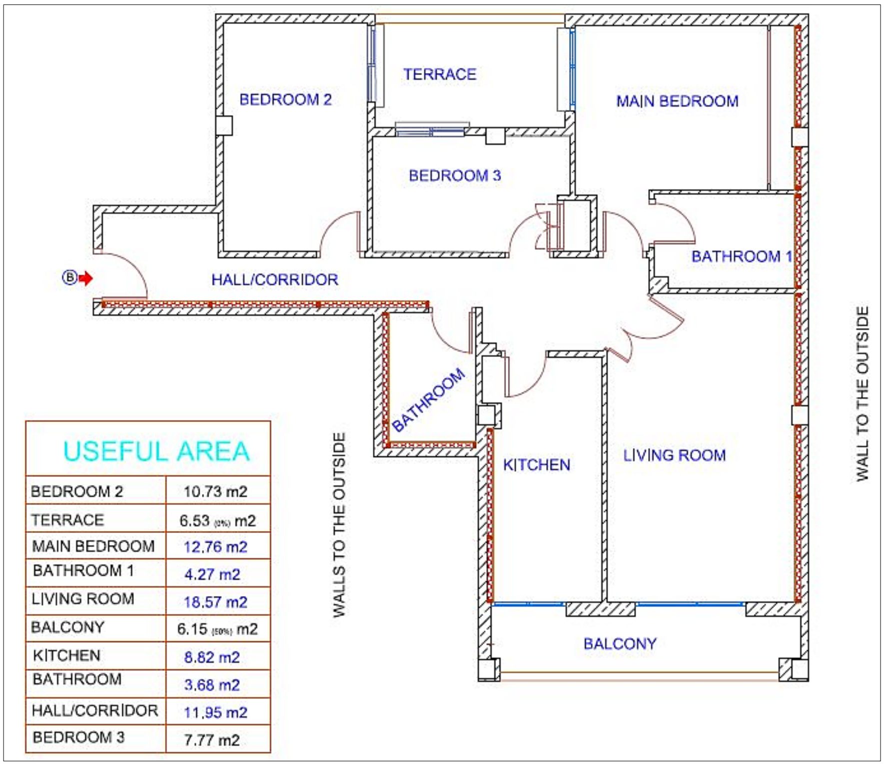
As well as, apply this measures to a real house is necessary to see how many square meters will be reduced if the insulation panel is put in the internal face of the wall.

For this topic, a house of 105 m2 of floor area is the object of our analysis. The house chosen for this demonstration has a useful area of 93.93 m2, where there are several walls to the outside that must be isolated for reducing the energy consumption of housing.

As can be seen below, the areas of the different rooms are included in a table to compare when the insulation is retrofitted outside or inside the wall.



Picture Nº 10: House drawing with external insulation. *(The Author, 2015)*



Picture Nº 11: House drawing with internal insulation. *(The Author, 2015)*

On the one hand, within the insulation will be more use of the area occupied by "thermal bridges". The problem is not easy to solve, easily lead to cracking, will also affect the speed of construction, affected residents re-decoration and interior suspension and fixed objects within the insulation structure is easy to destroy. Technically within the insulation irrationality, determine it's bound to be replaced by the outer insulation. *(Economic Theory, 2015).*

On the other hand, a disadvantage of internal insulation is that it reduces room space. This limits the permissible thickness of insulation in existing buildings. If room space is a factor, high-performance insulation may be preferred. *(Sustainable Energy Ireland, 2015)*

The total floor area of the external insulation house is 93.93 m2, while the area of the internal one is 2.70 m2 less, being a total of 91.23 m2.

After figuring out the reduction of living space, the search has been directed toward the price of a square meter in Germany, to know how much the house loses value. *(Global Property Guide, 2015).*

One square meter in Germany is around 4078 €, therefore the loss of 2.70 m2 means more than 11000 € of value. *(Global Property Guide, 2015).*

5.3 Energy efficiency.

To introduce this point, an image that reflects the temperature of the last 10 days of June will be shown below. Not only this variable will be taken into account, also, the humidity will have a significant impact on discussion of the results.

To make this point, perform the test temperature and humidity for 1 month was planned. Due to certain problems, the prediction of time was reduced to 15 days. Finally, it has not been possible to test the results before the deadline and all that will be developed next is only an estimate and possible assumptions of what the results should be shown.

The difficulty of monitoring the data send by the Data Logger to the computer, and the high cost of it, has made that the measurement has been reduced to 8 hours daily. Thus, comparing the levels will be more difficult, because according to the time zone, the temperature and humidity will have an influence less representative. This makes the study more precise, but at least an estimate will be obtained.

Picture Nº 12: Temperatures the last 10 days of June. *(Accuweather, 2015)*

This image is cut directly from the website Accuweather.com, retrieved June 21, 2015. The results are expected in a few days, and they will be compared to this data.

On the other hand, the moisture will be represented in a table with the information taken out from the same page that temperatures.

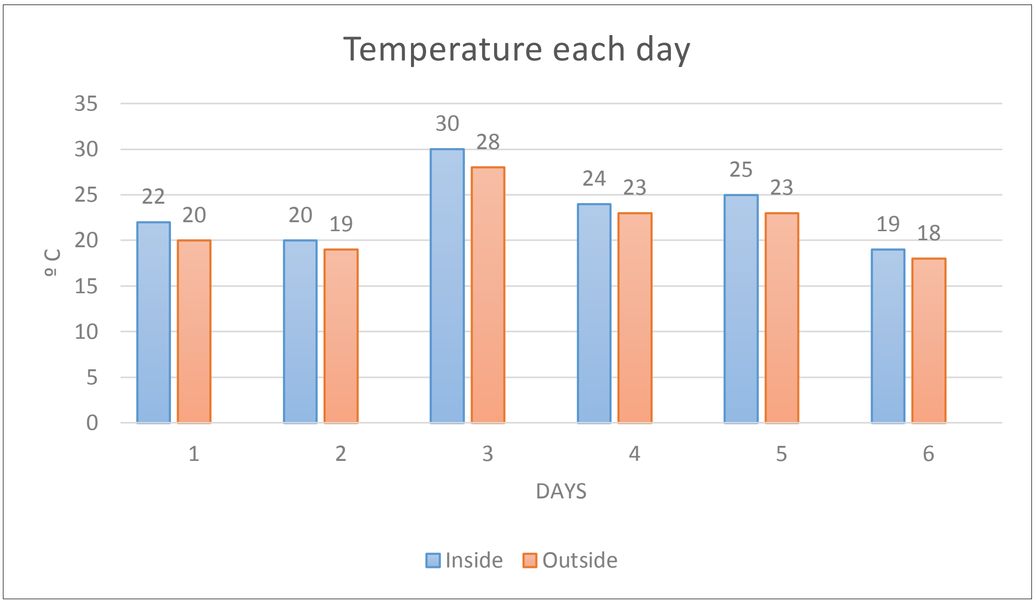
DAY (June)	21st	22nd	23rd	24th	25th	26th	27th	28th	29th	30ty
% MOISTURE	78%	71%	63%	55%	52%	51%	58%	54%	57%	55%

Table Nº 5: Humidity during the last 10 days of June. *(The Author, 2015 by Accuweather, 2015)*

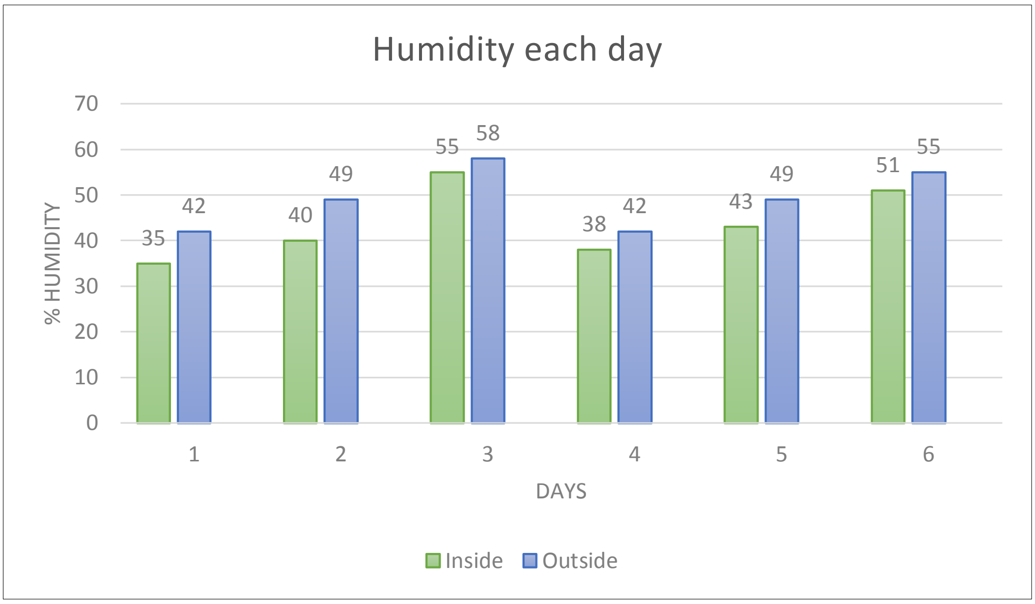
Once collected weather data from the website, it's time to show the results expected and which should be collected on the computer. Comparisons have been made using 2 tables, one for temperature and one for humidity, differentiating therein, the inner vapour layer and the outer one, these results will be analyze and discuss.

Such as to test panels has not been possible, and the results are unknown, in the graphs it was estimated data over a 6 days. It makes sense that the results are smaller than the data reflected in Mainz, and whom have been represented in an image and a table (temperature and humidity respectively).

Here, the expected results for the temperature values (Figure No. 6) and the corresponding to the moisture ones (Figure No. 7) are shown.



Graphic Nº 6: Comparison of the temperature results. *(The Author, 2015)*



Graphic Nº 7: Comparison of the humidity results. *(The Author, 2015)*

The idea of the preparation of this tables has been borrowed from the document called *Energy retrofitting of an old multi-storey building with heritage value. A case study in Copenhagen with full-scale measurements.* (Harrestrup, Svendsen and Papadopoulos, 2014). Unlike the previous study, in this report just the temperature and humidity has been analysed, no measuring values of energy consumption (kW/h).

Here, in these two comparable tables are shown the expected results for the sensor located outside and inside. The presented results are an estimation of the data obtained from the website where the temperature and humidity values have been extracted.

On one hand, if these results were really obtained, it would mean that the applied inside panel maintains the temperature and humidity in a better way that the retrofit outside panel. That's why, for a dwelling wouldn't be necessary cooling in summer and heating in winter as much as a dwelling with the panel retrofit on the outside.

However, on the other hand, perhaps the expected results are opposite to those shown in the graphs and the values obtained in the future, when the panels will be tested for long time, may be favourable to the outside of the wall.

Moreover, all this does not make sense if the analysis is not performed for a full year, then to be the study understood, is required as to reflect the different periods of time that occur in this country. That is, the different seasons, changes in temperature, humidity, the influence of rain, snow, etc.

Finally, the study was not focused on the selection of suitable insulating material in terms of price and performance variables. This could lower the cost and increase the insulation requirements for energy efficiency. *(Krus, Theuerkorn, GroBkinsKy and Künzel, 2014*)

5.4 Chapter Summary.

In the chapter of the discussion of the results, firstly, the economic and time-saving has been analysed. The time spent on the placement of the insulation is longer in the inside than in the outside and therefore, the inside method is more expensive. Furthermore, in turn, placing these panels reduces the useful area of those rooms that need to be isolated. Finally, the comparison between the expected temperature and humidity of the two panels is analysed to understand that even without being real, the application of this material represents an investment that is reflected in energy saving and therefore economical too.

An important point to note is that, in those buildings where the envelope cannot be altered, the insulation panel should be applied on the inner face.

6. CONCLUSIONS

The aim of this thesis was to validate and verify a model:

Timber frame panels with rock wool as insulation material with precast wooden cladding can be used to provide insulation to buildings to reduce energy consumption in a dwelling.

The questions arising from this statement were:

Question #1: *Can timber frames panels with rock wool provide insulation to buildings if these are applied on the outside or the inside?*

Question #2: *How was the study conducted to investigate the two methods and how many topics have been used for the discussion?*

Question #3: *Which of these two methods work better in each of the three major developed problems?*

To approach this problem, a literature review was conducted. The chapter “Literature Review” includes all the documents found and used for this report, with greater or lesser impact. For a better understanding, the variety of this information has been distributed into 3 groups. Web pages and Database is the first, the second called Technical Guides, Company Catalogues and Magazines and the last, based on Comparable Studies and Research Methods.

The method to validate and verify a model was experimental. In this case, a brief explanation for the 3 important topics developed, has been performed. Both the topic of energy efficiency, the reduction of floor and economic and time-saving, has been described how the investigation was conducted to get the results of each subchapter. In order to obtain the results of temperature and moisture was necessary the construction of two timber frame panels with rock wool as insulation material.

The data collection and analysis discusses through the use of graphic, the representation of the results that should be obtained from the temperature and humidity test. Four graphs show the expected results both the outside and the inside panel. Two graphic for the temperature, inside and outside, and the others for the moisture. Only the data is collected, so that can be analysed later.

The results were discussed in regard to their reliability and possible sources of error. Firstly, the economic and time- saving has been analysed. The time spent on the placement of the insulation is longer in the inside than in the outside and therefore, the inside method is more expensive. Furthermore, in turn, placing these panels reduces the useful area of those rooms that need to be isolated. Finally, the comparison between the expected temperature and humidity of the two panels is analysed to understand that even without being real, the application of this material represents an investment that is reflected in energy saving and therefore economical too.

The questions arising from the research aim can be answered as followed:

Question #1: *Can timber frames panels with rock wool provide insulation to buildings if these are applied on the outside or the inside?*

> Yes, the results expected won't be the same, but both methods can provide insulation to buildings, and reduce de energy consumption.

Question #2: *How was the study conducted to investigate the two methods and how many topics have been used for the discussion?*

> The investigation was based on three topics, the economic and time-saving, reduction of floor and energy efficiency. For each of these topics, a comparison between the outside method and the inside has been done.

Question #3: *Which of these two methods work better in each of the three major developed problems?*

> For the retrofitting of the panel in the external face of the wall, is necessary less money and time, and is profitable for the area of the dwelling. The disadvantage of the application of the outer panel, is that it should not be used when the building envelope cannot be altered. But, both inside and outside, the reduction of energy efficiency is notable.

Accordingly, the method has been validated and verified.

The retrofitting of timber-frames with insulation reduces the energy consumption of housing, it is a useful and simple method that can be used in most buildings.

6.1 Recommendations for future research.

As advice for the next researcher, for the improvement in the conduct of the report enabling it to validate and verify this model more accurately, would be ideally if:

- The study carried out will be made for 1 full year to compare data with all seasons, understanding the ups and downs and critics and optimal times of the panels.
- The study could be carried out with integrity in two houses with the same characteristics, which, if is possible, belong to the same building. Measuring in one of these, energy efficiency achieved with the outer insulation, and in the other dwelling, with the inner insulation, to be compared with the same weather.
- The study is focused on obtaining the optimum thickness of the timber frame, and the search for the ideal material, for that, without reducing thermal performance, the construction of these panels and their application to buildings involves a savings.
- The study provides a solution to the panels applied in the outside of the walls because many buildings cannot have aesthetic modifications in the envelope.

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