RepliCable and InnovaTive
Future Efficient Districts and cities

D2.3: Report on methods for determining the optimum insulation thickness

WP 2 , T 2.1

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Versions

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Abbreviations and Acronyms

BEST	Building Energy Specification Table
BIM	Building Information Modelling
CDD	Cooling Degree Day
CIFE	Stanford University Centre for Integrated Facilities Engineering
DD	Degree Day
Demo	Demonstration
DSI	Dynamic Systems Initiative
EPS	Expanded Polystyrene
EU	European Union
GHG	Greenhouse Gas
HDD	Heating Degree Day
HVAC	Heating Ventilation and Air Conditioning
ICS	International Classification for Standards
IPD	Integrated Project Delivery
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Analysis
LHV	Lower Heating Value
LULUCF	Land-use, Land-Use Change and Forestry
OECD	Organisation for Economic Co-operation and Development
PCM	Phase Change Materials
PEX	Cross-Linked Polyethylene
PWF	Present-Worth Factor
VIP	Vacuum Insulation Panels
WFW	Woven Fabric Waste
XPS	Extruded Polystyrene

0 Abstract

In the present work, a study to determine the insulation materials and the optimal thickness for the building envelope is presented. Thanks to this study, an economic and energy cost optimization can be addressed, which has positive effects on reducing the energy demand and GHG emissions.

In section 2 "*General approach to insulation"*, a revision of the state of the art about thermal insulation materials in buildings and related standards has been made. A general approach is given in order to understand the whole insulation system.

Section 3 "*Structure of global energy consumption"* presents an analysis of the evolution of the world energy consumption structure and energy sources used. The building materials industry is meeting the growing environmental concerns by developing innovative, green and efficient insulation materials, especially through eco-design concepts.

In section 4 "*Insulation thickness optimization studies"*, an optimum insulation thickness study is presented. The main goal of this study is to optimize the thermal insulation thickness based upon a degree-day heat loss analysis. A Building Information Modelling (BIM) platform was considered for its application on the thermal insulation, both on conventional and low temperature systems. Moreover, a method for calculating the optimum insulation thickness for building walls with respect to the heating degree-days for conventional systems has been developed. Finally, a method for determining the optimum insulation thickness for low temperature systems, based on analytical and numerical analysis, is presented.

In the last section, "*Implementation of insulation thickness optimization procedures in the demo-sites"*, a technical definition regarding insulation thickness in each demo site is given. This definition deals with the existing conditions of the buildings, such as wall structure or U-values. The concept of optimum thermal insulation thickness considers both the initial cost of the insulation and the energy savings over the life cycle of the insulation material. All the data related to Spanish, Turkish and Swedish demo sites were provided by different partners of CITyFiED consortium. For each demo site, the values are compared with the corresponding Building Energy Specification Table (BEST). In addition, GHG emissions values are given in order to estimate the environmental impact.

1 Introduction

WP2 aims to develop a systemic methodology for the renovation of large areas in the cities. The retrofitting actions can contribute to low energy and zero emission cities and urban areas, taking into account the technological availability for building retrofitting, deploying district heating networks and also integrating distributed power generation. Renewable energy sources and waste energy recovery play a key role in this approach towards a clean energy city strategy that reduces drastically the CO_2 emissions and primary energy use.

Under this framework, Subtask 2.1.3 *"Methods for determining insulation thickness"* focuses on determination of the insulation thickness for the building envelope. The main parameters considered for the optimization of the insulation thickness are the building characteristics, the HVAC systems, the climate area, the targeted energy saving and the investment cost.

1.1 Relationship with other WPs

Deliverable	Task	Relation
D2.1	T2.1	Definition of the key factors that affect energy consumption in residential districts and buildings.
D2.2	T2.1	Use of BIM for building retrofitting and optimal dosing.
D2.27	T2.3	Search of optimum values to improve the efficiency of the heating systems.
D4.1	T4.1	Technical information about the Spanish demo site
D4.2	T4.1	Technical information about the Turkish demo site
D4.2	T4.1	Technical information about the Swedish demo site
D4.21	T4.10	Calculation of energy performance and energy saving indicators

Table 1.1: Relationship with other WPs

1.2 Contribution from partners

Partner Short Name	Contributions
MIR	Optimum insulation thickness calculations and Life Cycle Cost Analysis (LCCA), document elaboration.
ITU	Application of building information modelling for thermal insulation.
CAR	Quality review and active contributor to the document contents as task coordinator.

Table 1.2: Contributions from partners

2 General approach to thermal insulation in buildings

Insulation comes from the Latin word for island (*insula*). Insulation is the noun describing a material that prevents the loss of heat, the intrusion of sound, or the passage of electricity to or from (something) by covering it in non-conducting material.

Thermal insulation systems can be composed by single materials or combination of them that, when properly applied, retard the rate of heat flow by conduction, convection and radiation. They retard the heat flow into or out of a building due to its high thermal resistance (1).

Many materials can be adapted to any size, shape or surface. A variety of finishes is used to protect the insulation from mechanical and environmental damage, and to enhance appearance. Thermal insulation of buildings is a significant factor in maintaining the thermal comfort of the building's users, particularly if we take extreme temperatures in winter and summer into consideration.

There are many benefits for using thermal insulation in buildings, which can be summarized as follows:

- A matter of principle: Using thermal insulation in buildings helps to reduce the reliance on mechanical/electrical systems to operate buildings comfortably and. Therefore, conserves energy and the associated natural resources. This matter of conserving natural resources is a common principle in all religions and human values.
- Economic benefits: An energy cost is an operating cost, and great energy savings can be achieved by using thermal insulation with little capital expenditure (only about 5% of the building construction cost). This does not only reduce operating cost but also reduces HVAC equipment initial cost due to reduced equipment size required.
- Environmental benefits: The use of thermal insulation not only saves energy operating cost, but also results in environmental benefits as reliance upon mechanical means with the associated emitted pollutants are reduced.
- Customer satisfaction and national good: Increased use of thermal insulation in buildings will result in energy savings which will lead to making energy available to others, to decreased customer costs, to fewer interruptions of energy services (better service), reduction in the cost of installing new power generating plants required in meeting increased demands of electricity, an extension of the life of finite energy resources and to the conservation of resources for future generations.
- Thermally comfortable buildings: The use of thermal insulation in buildings does not only reduce the reliance upon mechanical air-conditioning systems, but also extends the periods of indoor thermal comfort especially in between seasons.
- Reduced noise levels: The use of thermal insulation can reduce disturbing noise from neighbouring spaces or from outside. This will enhance the acoustical comfort of insulated buildings.

- Building structural integrity: High temperature changes may cause undesirable thermal movements, which could damage building structure and contents. Keeping buildings with minimum temperature fluctuations helps in preserving the integrity of building structures and contents. This can be achieved through the use of proper thermal insulation, which also helps in increasing the lifetime of building structures.
- Vapour condensation prevention: Proper design and installation of thermal insulation helps in preventing vapour condensation on building surfaces. However, care must be given to avoid adverse effects of damaging building structure, which can result from improper insulation material installation and/or poor design. Vapour barriers are usually used to prevent moisture penetration into low-temperature insulation.
- Fire protection: If the suitable insulation material is selected and properly installed. It can help in retarding heat and preventing flame immigration into building in case of fire (2).

2.1 The important terms for insulation

The following ones are the main terms and concepts related to thermal insulation:

- Thermal conductivity (k-value): Thermal conductivity is the time rate of steady state heat flow (W) through a unit area of 1 m thick homogeneous material in a direction perpendicular to isothermal planes, induced by a unit (1 K) temperature difference across the sample. Thermal conductivity, k-value, is expressed in W/mK. It is a function of material mean temperature and moisture content. Thermal conductivity is a measure of the effectiveness of a material in conducting heat. Hence, knowledge of the thermal conductivity values allows quantitative comparison to be made between the effectiveness of different thermal insulation materials
- Thermal resistance (R-value): Thermal resistance is a measure of the resistance of heat flow as a result of suppressing conduction, convection and radiation. It is a function of material thermal conductivity, thickness and density. Thermal resistance, R-value, is expressed in m^2K/W.
- Thermal conductance (C-value): Thermal conductance is the rate of heat flow (W) through a unit surface area of a component with unit (1 K) temperature difference between the surfaces of the two sides of the component. It is the reciprocal of the sum of the resistances of all layers composing that component without the inside and outside air films resistances. It is similar to thermal conductivity except it refers to a particular thickness of material. Thermal conductance, C-value, is expressed in W/m^2K
- Thermal transmittance (U-value): Thermal transmittance is the rate of heat flow through a unit surface area of a component with unit (1 K) temperature difference between the surfaces of the two sides of the component. It is the reciprocal of the sum of the resistances of all layers composing that component plus the inside and outside air films resistances. It is often called the Overall Heat Transfer Coefficient, U-value, and is expressed in W/m^2K.

Thermal insulating materials resist heat flow as a result of the countless microscopic dead air-cells, which suppress (by preventing air from moving) convective heat transfer. It is the air entrapped within the insulation, which provides the thermal resistance, not the insulation material. Creating small cells (closed cell structure) within thermal insulation across which the temperature difference is not large also reduces radiation effects. It causes radiation 'paths' to be broken into small distances where the long-wave infrared radiation is absorbed and/or scattered by the insulation material (low-e materials can also be used to minimize radiation effects). However, conduction usually increases as the cell size decreases (the density increases).

Typically, air-based insulation materials cannot exceed the R-value of still air. However, plastic foam insulations (e.g. polystyrene and polyurethane) use fluorocarbon gas (heavier than air) instead of air within the insulation cell, which gives higher R-value. Therefore, the interactions of the three modes of heat transfer of convection, radiation, and conduction determines the overall effectiveness of insulation and is represented by what is called the apparent thermal conductivity which indicates the lack of pure conduction especially at high temperatures.

Both vapour passage and moisture absorption are more critical in open cell structure insulation as compared to closed cell structure. Vapour retarders are commonly used to prevent moisture penetration into low-temperature insulation. Vapour retarders are used to the inside of insulation in cold climates and to the outside of insulation in hot and humid climates (allowing moisture escape from the other side). Vapour retarder's placement, however, is a challenge in mixed climates.

2.2 General description of thermal insulation materials

There are many types of building thermal insulation available which can be grouped under the following basic materials and composites.

Inorganic Materials		Organic Materials	
Fibrous Materials	Cellular Materials	Fibrous Materials	Cellular Materials
− Glass wool − Rock wool − Ceramic wool − Slag wool	− Calcium silicate − Bonded perlite − Vermiculite − Ceramic products	− Cellulose − Cotton − Wood − Pulp − Cane − Synthetic fibres	− Cork − Foamed rubber − Polystyrene − Polyurethane − Polyisocyanurate − Polyethylene − Other polymers

Table 2.1: Classification of insulation materials

Accordingly, the insulating materials are produced in the following different forms:

- Mineral fibre blankets: batts and rolls (fiberglass and rock wool)
- Loose fill that can be blown-in (fiberglass. rock wool), poured-in, or mixed with concrete (cellulose. perlite. vermiculite)
- Rigid boards (polystyrene. polyurethane. polyisocyanurate. and fiberglass)
- Foamed or sprayed in-place (polyurethane and polyisocyanurate)
- Boards or blocks (perlite and vermiculite)
- Insulated concrete blocks
- Insulated concrete form
- Reflective materials (aluminium foil, ceramic coatings)

2.2.1 Common used thermal insulation materials

Mineral wool

Mineral wool (or stone wool) is a non-metallic, inorganic product manufactured using stone/rock (volcanic rock, typically basalt or dolorite) together with blastfurnace or steel slags as the main components (typically 97%). The remaining 2-3% organic content in the product as sold is generally a thermosetting resin binder (adhesive) and a little oil.

In the manufacture of mineral wool insulation, rock material and two slag materials (blastfurnace slag and steel slag) are melted in a cupola furnace at approximately 1,500 °C) (3).

Typical thermal conductivity values for mineral wool are between 30 and 40 mW/(mK). The thermal conductivity of mineral wool varies with temperature, moisture content and mass density.

Figure 2.1: Mineral Wool

As an example, the thermal conductivity of mineral wool may increase from 37 mW/(mK) to 55 mW/(mK) with increasing moisture content from 0 vol% to 10 vol% respectively. Mineral wool products may be perforated and also cut and adjusted at the building site, without any loss of thermal resistance (4).

Expanded polystyrene (EPS)

Expanded polystyrene (EPS) foam is a closed-cell insulation that's manufactured by "expanding" a polystyrene polymer; the appearance is typically a white foam plastic insulation material (5).

Typical thermal conductivity values for EPS are between 30 and 40 mW/(mK). The thermal conductivity of EPS varies with temperature, moisture content and mass density.

Figure 2.2: EPS

As an example, the thermal conductivity of EPS may increase from 36 mW/(mK) to 5 4mW/(mK) with increasing moisture content from 0 vol% to 10 vol%, respectively. EPS products may be perforated and also cut and adjusted at the building site, without any loss of thermal resistance.

Extruded polystyrene (XPS)

Extruded polystyrene (XPS) foam is a rigid insulation that's also formed with polystyrene polymer, but manufactured using an extrusion process and is often manufactured with a distinctive colour to identify the product brand (5).

Typical thermal conductivity values for XPS are between 30 and 40 mW/(mK). The thermal conductivity of XPS varies with temperature, moisture content and mass density.

As an example, the thermal conductivity of XPS may increase from 34 mW/(mK) to 44 mW/(mK) with increasing moisture content from 0 vol% to 10 vol%, respectively. XPS products may be perforated, and also cut and adjusted at the building site, without any loss of thermal resistance (4).

Figure 2.3: XPS

Cork

Cork is a natural material, with wonderful haptic and olfactory qualities with the versatility to be easily carved, cut, shaped and formed. (6)

Cork thermal insulation is primarily made from the cork oak, and can be produced as both a filler material or as boards. Typical thermal conductivity values for cork are between 40 and 50 mW/(mK).

Cork insulation products may be perforated, and also cut and adjusted at the building site, without any loss of thermal resistance (4).

Figure 2.4: Cork

Polyurethane (PUR)

Figure 2.5: Polyurethane

Rigid polyurethane foam is a closed-cell plastic. It is used as factory-made thermal insulation material in the form of insulation boards or block foam and in combination with various rigid facings as a constructional material or sandwich panel. PUR may also be used as expanding foam at the building site, e.g. to seal around windows and doors and to fill various cavities.

Typical thermal conductivity values for PUR are between 20 and 30 mW/(mK), i.e. considerably lower than mineral wool, polystyrene and cellulose products. The thermal conductivity of PUR varies with temperature, moisture content and mass density.

As an example, the thermal conductivity of PUR may increase from 25 mW/(mK) to 46 mW/(mK) with increasing moisture content from 0 vol% to 10 vol%, respectively. PUR products may be perforated, and also cut and adjusted at the building site, without any loss of thermal resistance. (4)

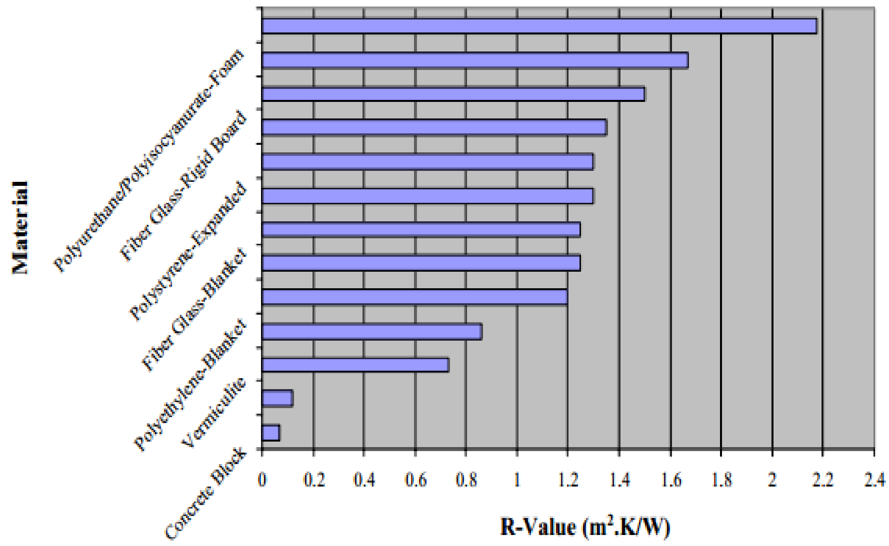


Figure 2.6: R-values of different materials

Figure 2.6 shows a graphical comparison of the thermal resistances of 5 cm thickness for common building insulation materials.

*Concrete block is not considered as an insulating material. However, it was included in the figure as a reference (no insulation case) for comparison purposes only.

2.2.2 State-of-the-art thermal building insulation

Vacuum insulation panels (VIP)

VIP consists of an open porous core of fumed silica enveloped of several metallized polymer laminate layers.

It's thermal conductivities ranging from between 3 and 4 mW/(mK) in fresh condition to typically 8 mW/(mK) after 25 years ageing due to water vapour and air diffusion through the VIP envelope.

Thermal conductivities between 5 and 10 times, depending on ageing time, lower than traditional thermal insulation materials like mineral wool and polystyrene products will especially be important when trying to achieve the standard and requirements of passive houses and zero energy or zero emission buildings.

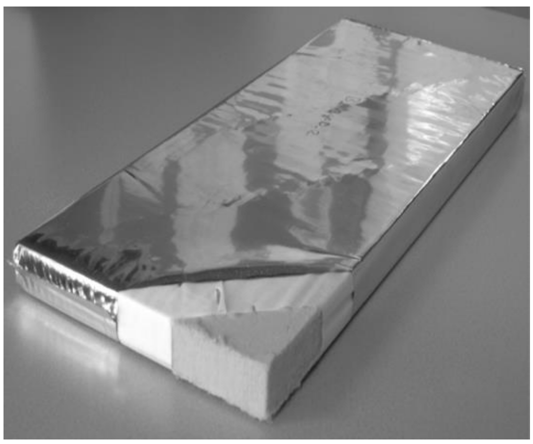


Figure 2.7: VIP insulation material

Aerogels

Aerogels represent a state-of-the-art thermal insulation solution, and may be the most promising with the highest potential of them all at the moment.

- Aerogel enables boards with ultra-low thermal conductivity - as low as 15 mW/mK (2-2.5 times lower than traditional insulation materials)
- Aerogel-enabled boards require 2-3 times less space than traditional insulation boards for the same performance
- Aerogel boards are extremely open to moisture but repel liquid water for reduced risk of mildew issues or structural damage (7)

The production costs of aerogels are still very high. Aerogels have relatively high compression strength, but is very fragile due to its very low tensile strength. The tensile strength may be increased by incorporation of a carbon fibre matrix.

A very interesting aspect with aerogels is that they can be produced as either opaque, translucent or transparent materials, thus enabling a wide range of possible building applications. For aerogels to become a widespread thermal insulation material for opaque applications, the costs have to be lowered substantially (4).

Also, the use of aerogel in walls, floors, and roofs can help a building meet even the most difficult requirements of the Passive House, LEED Platinum standards, as well as ever more strict regional requirements (7).

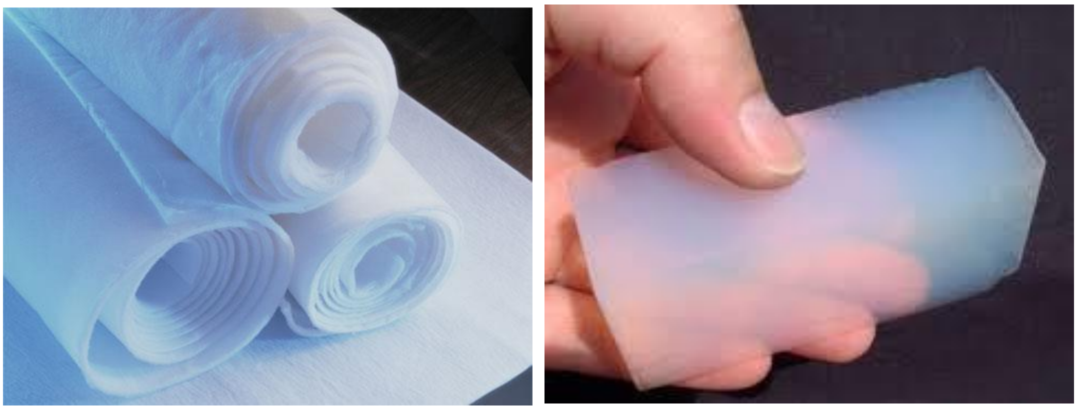


Figure 2.8: Aerogel

Phase change materials (PCM)

The PCM insulation to be demonstrated is made by combining cellulose insulation with hard shell polymer microcapsules (2-20 microns in diameter) that contain organic fatty acids and fatty acid esters as core materials. The core materials change phase from solid to a liquid or semi-liquid to prevent excessive heat flow and maintain comfortable temperatures; they exhibit a “thermal mass effect”, i.e., capacity to store energy as latent heat.

On very hot days the PCM will prevent outside heat from entering the building by changing phase to soak up the extra heat, thus reducing the cooling load. On cold days, the PCM helps to conserve heat energy escaping into the walls, by storing that energy as “latent heat”. The latent heat is released back into the building as "sensible heat" when the temperature drops at night.

The innovative PCM-based insulation technology is expected to enhance energy efficiency in heating and cooling buildings in moderate climates by reducing excess sensible heat in the summer and reducing heat loss in the winter. The anticipated cost of this technology is 40% greater than the cost of standard insulation; however, the technology is expected to save 30% of the annual cost of energy for heating and cooling (8).

2.2.3 Possible future thermal insulation materials

With growing environmental concerns, building materials industry heads for innovative, green and efficient insulation materials especially for the passive house and eco-design concepts. There have been many recent researches done on innovative insulation materials. Most of the recent studies that focus on innovative solution for insulation materials use Life Cycle Assessment to analyse these solution from the perspective of environmental advantages in addition to economic advantages, such as reduced dependence on non-renewable energy/material sources, lower pollutant and greenhouse gas emissions, enhanced energy recovery and end of life biodegradability of components.

The innovative insulation materials examples are as follows;

- Binderless cotton stalk fibreboard (BCSF) (9)
- Coal fly ash and scrap tire fibre (10) (11)
- Woven fabric waste (WFW) (12)
- Eco-sandwich (Composed of cork. flax fibres and bio-based epoxy resin) (13)
- Bast fibres & hemp (14)
- Composition of chitosan and sunflower stalks (15)
- Nano insulation materials (NIMs) (16)
- Boards made from coconut husk and bagasse (17)
- The cake formed of sunflower (18)
- Sheep’s wool (19)
- Wild and domestic silkworm cocoons (20)
- PET bottle and automobile tire pieces (21)
- Dynamic insulation materials and load bearing insulation materials (4)

2.3 General description of thermal insulation standards

The International Classification for Standards (ICS) is an international classification system for technical standards. The ICS serves as a structure for catalogues and databases of technical standards and other normative documents, and as a basis for standing-order system for international, regional and national standards.

The ICS uses a hierarchical classification, which consists of three nested levels called fields, groups and sub-groups. All classification levels are designated by a classification code. (22)

As an example:

- 91: Construction materials and building
- 91.120: Protection of and in buildings
- 91.120.10: Thermal insulation of buildings

ISO 9972:2006. Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method

ISO 9972:2006 is intended for the measurement of the air leakage of building envelopes of single-zone buildings. For the purpose of ISO 9972:2006, many multi-zone buildings can be treated as single-zone buildings by opening interior doors or by inducing equal pressures in adjacent zones

ISO 13786: 2007. Thermal performance of building components: Dynamic thermal characteristics - Calculation methods

ISO 13786:2007 specifies the characteristics related to the dynamic thermal behaviour of a complete building component and provides methods for their calculation. It also specifies the information on building materials required for the use of the building component. Since the characteristics depend on the way materials are combined to form building components. ISO 13786:2007 is not applicable to building materials or to unfinished building components.

ISO 12241: 2008. Thermal insulation for building equipment and industrial installations: Calculation rules

ISO 12241:2008 gives rules for the calculation of heat-transfer-related properties of building equipment and industrial installations, predominantly under steady-state conditions. ISO 12241:2008 also gives a simplified approach for the treatment of thermal bridges.

ISO 10077-1:2006. Thermal performance of windows, doors and shutters -- Calculation of thermal transmittance - Part 1: General

ISO 10077-1:2006 specifies methods for the calculation of the thermal transmittance of windows and pedestrian doors consisting of glazed and/or or opaque panels fitted in a frame, with and without shutters.

Thermal bridge effects at the rebate or joint between the window or door frame and the rest of the building envelope are excluded from the calculation. The calculation also does not include effects of solar radiation, heat transfer caused by air leakage, calculation of condensation, ventilation of air spaces in double and coupled windows and surrounding parts of an oriel window.

ISO 13370:2007. Thermal performance of buildings - Heat transfer via the ground - Calculation methods

ISO 13370:2007 provides methods of calculation of heat transfer coefficients and heat flow rates for building elements in thermal contact with the ground, including slab-on-ground floors, suspended floors and basements. It applies to building elements, or parts of them, below a horizontal plane in the bounding walls of the building situated.

- For slab-on-ground floors, suspended floors and unheated basements at the level of the inside floor surface;
- For heated basements, at the level of the external ground surface.

ISO 13790:2008. Energy performance of buildings-Calculation of energy use for space heating and cooling

ISO 13790:2008 gives calculation methods for assessment of the annual energy use for space heating and cooling of a residential or a non-residential building, or a part of it, referred to as “the building”.

This method includes the calculation of:

- The heat transfer by transmission and ventilation of the building zone when heated or cooled to constant internal temperature;
- The contribution of internal and solar heat gains to the building heat balance;
- The annual energy needs for heating and cooling. to maintain the specified set-point temperatures in the building – latent heat not included;
- The annual energy use for heating and cooling of the building, using input from the relevant system standards referred to in ISO 13790:2008.

ISO 23993:2008. Thermal insulation products for building equipment and industrial installations - Determination of design thermal conductivity

ISO 23993:2008 gives methods to calculate design thermal conductivities from declared thermal conductivities for the calculation of the thermal performance of building equipment and industrial installations.

ISO 12655:2013. Energy performance of buildings - Presentation of measured energy use of buildings

ISO 12655:2013 sets out a consistent methodology to present energy use in buildings, which is specified clearly with the energy usage, corresponding boundary and the energy data (presented with original energy carriers or equivalent energy).

ISO 15099:2003. Thermal performance of windows, doors and shading devices - Detailed calculation

ISO 15099:2003 specifies detailed calculation procedures for determining the thermal and optical transmission properties (e.g. thermal transmittance and total solar energy transmittance) of window and door systems based on the most up-to-date algorithms and methods, and the relevant solar and thermal properties of all components.

ISO 13787:2003. Thermal insulation products for building equipment and industrial installations - Determination of declared thermal conductivity

ISO 13787:2003 establishes a procedure for the determination and verification of declared thermal conductivity, as a function of temperature, of thermal insulating materials and products used for the insulation of building equipment and industrial installations. (23)

EN 832: 2000 Thermal performance of buildings - Calculation of energy use for heating - Residential buildings

This standard gives a simplified calculation method for assessment of the heat use and energy needed for space heating of a residential building, or a part of it, which will be referred to as the building.

This method includes the calculation of:

- The heat losses of the building when heated to constant temperature.
- The annual heat needed to maintain the specified set-point temperatures in the building.
- The annual energy required by the heating system of the building for space heating.

The building may have several zones with different set-point temperatures. One zone may have intermittent heating.

The calculation period may be either the heating season or a monthly period. Monthly calculation gives correct results on an annual basis, but the results for individual months close to the end and the beginning of the heating season may have large relative errors.

3 Structure of global energy consumption

Energy is essential for economic and social development and improved quality of life in all countries. Energy is defined as the ability to do work and it can be found in different forms such as chemical. Thermal, electricity, mechanical, gravitational, nuclear, radiant, sound and motion. Energy can be stored/converted and/or amplified depending on the application.

Energy demand started with the Industrial Revolution. European energy need increased in parallel to growing technology and started to emphasis on the importance for the most needed concept day by day.

Energy is of importance for the economic and social community. After the energy crisis occurred in 1970s, the importance of energy increased for the countries. The saving energy use studies started. The countries which have natural sources conducted studies to use their resources in the best way. Other countries tried to create various technics. Consequently renewable energy forms emerged.

Global primary energy demand rises by around one-third in the period now until 2035. Driven mainly by Asian countries and the Middle East, oil and coal consumption grow more slowly than the overall rise in energy demand (12% and 16%), while natural gas, nuclear and modern renewables rise more quickly (44% and 74% and 134%). Despite low or zero-carbon energy sources meeting 45% of the growth in primary energy demand, the share of fossil fuels in primary energy demand falls only gradually from its current 82% to a 76% share by 2035.

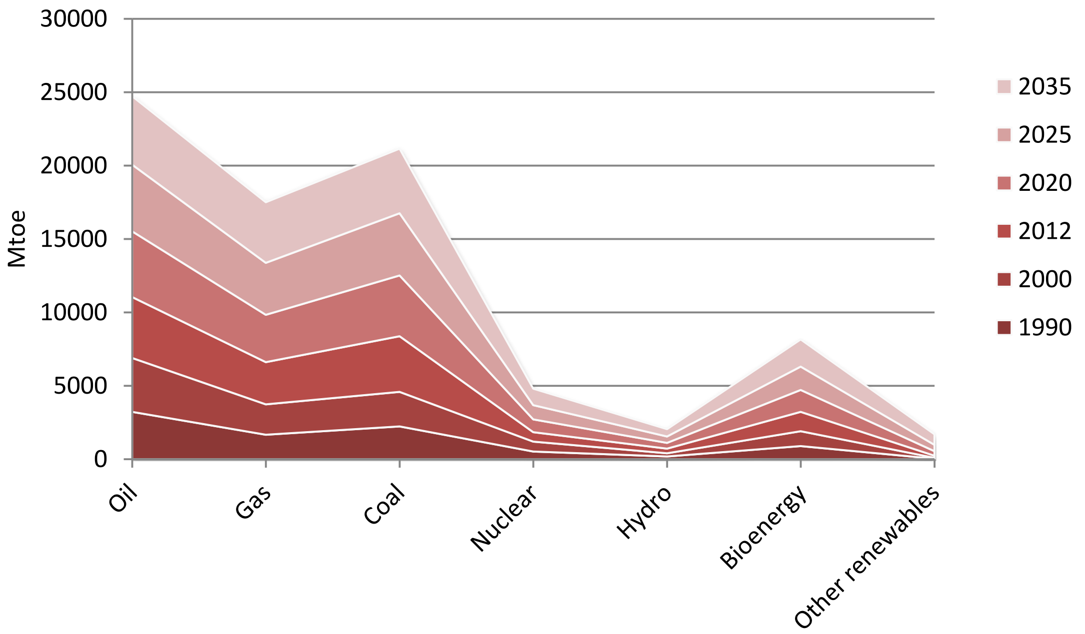


Figure 3.1: World primary energy demand by fuel and energy-related CO_2 emissions (24)

	1990	2000	2012*	2020	2025	2030	2035	2012-2035**
Oil	3231	3663	4158	4469	4545	4600	4666	0.5%
Gas	1668	2072	2869	3134	3537	3824	4127	1.6%
Coal	2230	2357	3796	4137	4238	4309	4398	0.6%
Nuclear	526	676	642	869	969	1051	1118	2.4%
Hydro	184	225	313	391	430	466	501	2.1%
Bioenergy***	893	1016	1318	1488	1598	1718	1848	1.5%
Other renewables	36	60	142	311	432	566	717	7.3%
Total (Mtoe[2])	**8769**	**10070**	**13240**	**14899**	**15749**	**16534**	**17376**	**1.2%**
Fossil fuel share	81%	80%	82%	79%	78%	77%	76%	n.a.
Non-OECD[3]	4047	4506	7606	9019	9859	10623	11406	1.8%
OECD	4522	5292	5271	5478	5461	5455	5484	0.7%
CO_2 emissions (Gt)	**20.9**	**23.7**	**31.5**	**34.3**	**35.4**	**36.2**	**37.2**	**0.7%**

* 2012 data are preliminary estimates. ** Compound average annual growth rate. *** Includes traditional and modern biomass uses. Notes: Non-OECD and OECD totals exclude international bunkers

Table 3.1: World primary energy demand by fuel and energy-related CO_2 emissions (24)

Total GHG emissions (excluding LULUCF) in the EU decreased substantially since 1990, reaching their lowest level in 2012. The EU emitted 4,544 million tonnes of CO_2 eq. in 2012, accounting for less than 10% of global GHG emissions. Table 3.2 shows the total greenhouse gas emissions in the period 1990– 2012, both in the EU-15 (which is collectively a party to the Kyoto Protocol) and in the EU-28.

The EU-15 as Party to the Kyoto Protocol accounts for 80% of EU-28 GHG emissions. Almost 50% of the EU net decrease in GHG emissions was accounted for by Germany and the United Kingdom. The main reasons for the favourable trend in Germany were increasing efficiency in power and heating plants and the economic restructuring of the five new Länder after the German reunification. Lower GHG emissions in the United Kingdom were primarily the result of liberalising energy markets and the subsequent fuel switch from oil and coal to gas in electricity production (25).

[2] Million Tonnes of Oil Equivalent

[3] Organisation for Economic Co-operation and Development

	Countries	1990	Kyoto Protocol base year	2012	Change base year-2012	Targets 2008-2012 under Kyoto Protocol and "EU burden sharing"
EU-15	Austria	78.1	79.0	80.1	1.3%	-13.0%
	Belgium	143.0	145.7	116.5	-20.0%	-7.5%
	Denmark	68.7	69.3	51.6	-25.5%	-21.0%
	Finland	70.3	71.0	61.0	-14.1%	0.0%
	France	557.4	563.9	490.1	-13.1%	0.0%
	Germany	1248.0	1232.4	939.1	-23.8%	-21.0%
	Greece	4.9	107.0	111.0	3.7%	25.0%
	Ireland	55.2	55.6	58.5	5.3%	13.0%
	Italy	519.1	516.9	460.1	-11.0%	-6.5%
	Luxembourg	12.9	13.2	11.8	-10.1%	-28.0%
	Netherlands	211.8	213.0	191.7	-10.0%	-6.0%
	Portugal	60.8	60.1	68.8	14.3%	27.0%
	Spain	283.7	289.8	340.8	17.6%	15.0%
	Sweden	72.7	72.2	57.6	-20.2%	4.0%
	United Kingdom	775.7	776.3	580.8	-25.2%	-12.5%
EU-28	Bulgaria	109.1	132.6	61.0	-54.0%	-8.0%
	Croatia	31.9	31.3	26.4	-15.7%	-5.0%
	Cyprus	6.1	n.a.	9.3	n.a.	n.a.
	Czech Republic	196.1	194.2	131.5	-32.3%	-8.0%
	Estonia	40.6	42.6	19.2	-55.0%	-8.0%
	Hungary	97.6	115.4	62.0	-46.3%	-6.0%
	Latvia	26.2	25.9	11.0	-57.6%	-8.0%
	Lithuania	48.7	49.4	21.6	-56.2%	-8.0%
	Malta	2.0	n.a.	3.1	n.a.	n.a.
	Poland	466.4	563.4	399.3	-29.1%	-6.0%
	Romania	247.7	278.2	118.8	-57.3%	-8.0%
	Slovakia	73.2	72.1	42.7	-40.7%	-8.0%
	Slovenia	18.4	20.4	18.9	-7.1%	-8.0%

Table 3.2: Greenhouse gas emissions in CO_2 equivalents (excl. LULUCF) (25)

A projection of the future energy consumption is a vital input to analyse economic, energy, and environmental policies. An outlook on the future energy consumption helps us decide on future energy investment. It is very important that the prediction of future energy consumption be as accurate as possible.

In the last decade, the energy industry has been facing major changes mostly because of concerns about sustainability. Countries worldwide, especially industrialized nations, have been forced to improve the energy efficiency in several sectors with high energy consumption. The building industry is a major sector for energy consumption in the world. In the developed world, buildings are responsible for as much as 50% of the total energy consumption, and space heating and cooling together have the biggest share in the residential consumption. (26)

The energy consumption of buildings has become a relevant international issue and different policy measures for energy saving are under discussion in many countries. In the EU, buildings account for about the 40% of the total energy consumption and they represent the largest sector in all end-users area, followed by transport with the 33% (27); whereas in terms of CO_2 emission, buildings are responsible for about 36% of it. It is estimated that the residential sector alone represented about 25% (in 2011) of the final energy consumption in EU. (28)

Energy in households is consumed for different purposes, such as hot water, cooking and appliances, but the dominant energy end-use in Europe (responsible for around 70% of total consumption in households) is space heating. Moreover, trend in energy demand, both for heating and cooling purpose, assumes a relevant issue on the development of energy systems and energy policies. Energy demand for heating and cooling purposes tends to rise in the 21th century, especially due to the increasing income in developing countries and to the climate change. In particular, the climate change has a double effect: firstly, it decreases the global heating energy demand by over a 30% and, secondly, it increases cooling energy demand by about 70%. (26)

Among all the solutions proposed to the energy problems in buildings, experts agree that building insulation is the least-cost option for reducing energy consumption and CO_2 emissions. The determination of the optimum thickness of the building insulation materials has been a subject of interest for many years among the scientific community. The optimum insulation thickness depends on a large number of parameters. The scientific studies are primarily focused on analysing the effect of the climatic parameters, the orientation, the thermal mass, the fuels and other parameters. (29)

Effective thermal insulation of residential envelope plays an important role in the reduction of heat flow rate and energy consumption for space cooling and heating. The selection of insulation material is based on the thermal conductivity and price. The increase of insulation thickness will decrease the energy consumption for cooling and heating, however, the investment for the insulation will increase as well, and then there must be an optimum point where the total investment cost for the insulation and energy consumption can be minimized over the lifetime. Therefore, the selection of proper insulation materials, as well as the determination of optimum insulation thickness is critical for the economic analysis. (30)

Many people overlook the importance of insulation in the process industry. For industrial facilities such as power plants, refineries and paper mills, mechanical thermal insulations are installed to control heat gain or heat loss on process piping and equipment, steam and condensate distribution systems. While placing insulation onto a pipe is a fairly easy, resolving issue such as what type of insulation to use and how much is not so easy. Insulation is available in nearly any material imaginable. The most important characteristics of any insulation material include a low thermal conductivity.

In the process industry, the most common insulators are various types of calcium silicate or fiberglass. Calcium silicate is generally more appropriate for temperatures above 225 ºC, while fiberglass is generally used at temperatures below 225 ºC. (26)

4 Insulation thickness optimization studies

The main goal of the insulation thickness studies is to optimize thermal insulation thickness based on degree-day heat loss analysis. The concept of optimum thermal insulation thickness considers both the initial cost of the insulation and the energy savings over the life cycle of the insulation material. The optimum insulation thickness corresponds to the value that provides minimum total life cycle cost. The analyses for optimum insulation thickness are commonly based on some parameters such as heating and cooling loads, the cost and the lifetime of the insulation materials, efficiencies of heating and cooling systems and the inflation rate. However, heating and cooling demands of buildings are mostly considered sufficient input parameters in order to perform an optimization work. In literature, generally the degree-day or degree-hour concept is used to predict the heating and cooling loads of buildings since the approach is quite simple. However, there are also some theoretical methods for investigating transient thermal behaviour of building fabrics.

4.1 Application Building Information Modelling tools in insulation thickness optimization studies

BIM is a work method based on the collaboration of all project participants on the same model, which is a digital representation of the physical and functional characteristics of a construction project.

This work method makes it easier to share data (communication), working using shared data (collaboration), conduct pre-construction analysis (simulation) and use these results to improve design and implementation (optimization).

In other words, BIM platform has the main role to compose a guideline to perform each phase of the process with a range of indicators for assessing objectively the applicable technology to support decision making through the design process.

BIM has the real role in the integrated project delivery (IPD) process. BIM and web-based project management software has created a solid platform for an improved, more efficient means of collaboration between all the parties involved in project delivery.

On the other hand, IPD is an emerging method that provides collaboration at the earlier stages for more efficient results by integrating all the stakeholders within the project, systems that are planned to be used, business structures and practices into the process in order to minimize waste and maximize progress efficiency through all phases of the project. Incorporation of the BIM tools into the IPD process levels enable stakeholders to use information about the project in more integrated way. Thus it increases the result efficiency through involving their creativity to provide more sustainable designs. (31)

Basically, BIM let produce and direct the data of buildings during its life cycle. Typically it uses three-dimensional, real-time, dynamic building modelling software to increase productivity in building design and construction. The process produces the building information model which encompasses building geometry, spatial relationships, geographic information, and quantities and properties of building components. Hovever, BIM is known as 5D modelling, since it consists of three geometric dimensions plus the dimensions of time (4D) and costs (5D).

Teamwork collaboration will be based on a BIM approach, the methodology will offer guidelines enabling the collaborative work and for the correct application of the available methods and tools for manage the process and to calculate energy savings. BIM is a technique which requires co-work of all members involved in the same model, which is a digital representation of the physical and functional characteristics of a construction project.

A BIM can be used for the following purposes (further developed in points 4.3 and 4.4, regarding insulation applications):

- Visualization: 3D renderings can be easily generated with little additional effort.
- Forensic analysis: a building information model can easily be adapted to graphically illustrate potential failures, leaks, evacuation plans, etc.
- Facilities management: facilities management departments can use BIM for renovations, space planning, and maintenance operations.
- Cost estimating: BIM software have built-in cost estimating features. Material quantities are automatically extracted and updated when any changes are made in the model.
- Construction sequencing: a building information model can be effectively used to create material ordering, fabrication, and delivery schedules for all building components. (32)

Based on a BIM approach, the methodology will offer interoperability with energy simulation tools to calculate energy performance of the district before and after insulation applications such as Revit, AutoCAD and e-Quest, which are the main BIM tools used in order to see insulation application results in the current situation and post implementation. They are essential when analysing the cost-effectiveness of the different priority design strategies or proposals by comparing it with the base case scenario.

The three key levels of the methodology of BIM

The first level of the methodology of BIM is the management level, which assures the correct involvement of the stakeholders in the project steps. It also provides efficient communication network between the stakeholders. The second level is the technical level, that identifies the needs and opportunities of the district, determines the technological solutions for real needs and the correct application of those technologies. The third level is the DSI Platform, a controlling platform which considers whether energy goals are met or not and if the progress goes ahead. In addition, it provides recommendations in terms of performance, cost effectiveness and conform of the technologies.

Management Level

During the diagnosis phase, the socio economic profile must be searched out in order to specify clients' needs, building demands and required comfort conditions. It's important to identify the user expectations in a social ways in terms of insulation. Based on IPD principles that are already set for each CITyFiED demo site, the management platform will guarantee the proper involvement of all stakeholders and development of their communication flows between phases. In the case of insulation; architects, engineers (mechanicals, electronic, civil etc.) and energy performance analysers are involved through the process as the technical team. Preparation of "District Audit Report" enables finishing the diagnosis phase in order to go through design phase.

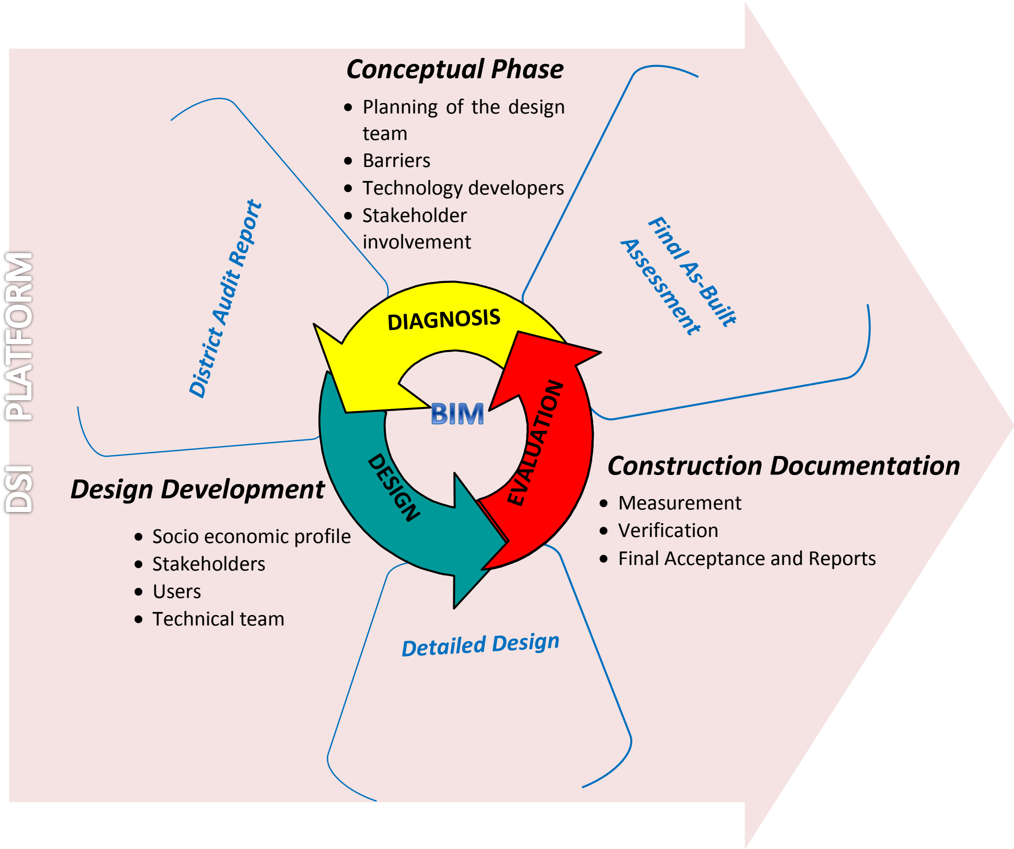


Figure 4.1: Management level of BIM structure

In the design phase, the design team which works on insulation thickness is defined and this team consists of engineers and architects. Then, the barriers related with insulation thickness are determined to overcome. When the barriers identified and solved, proper insulation material which has optimum thickness according to the optimization studies is implemented to the external walls with the help of technology developers to the design team. After the implementation is over, management of negotiation process starts with the involvement of all stakeholders.

In the execution and evaluation phases, a measurement and verification plan should be done and final acceptance and reports must be evaluated in order to apply final as-built assessment before going through the technical level of the project.

Technical Level

In the diagnosis phase, technical level progress starts with the identification of the targets and goals.

Data collection for the technical level is possible by the involvement of users during the management level. Data collection and its analysis within the technical level can be classified in three aspects:

- Environmental aspect: Typological aspect: analysis of environmental conditions related to the project site
- Typological aspect: analysis of specific building aspects linked their typology
- Detailed aspect: detailed analysis of building types, energy specification and flows

All three levels are highly important for technical teams in terms of insulation. Thus they allow global definition for which data have to be used for the diagnosis of insulation material and application method choice for the project, the involvement of heating bills that belongs to the current case is also necessary within the collection of data.

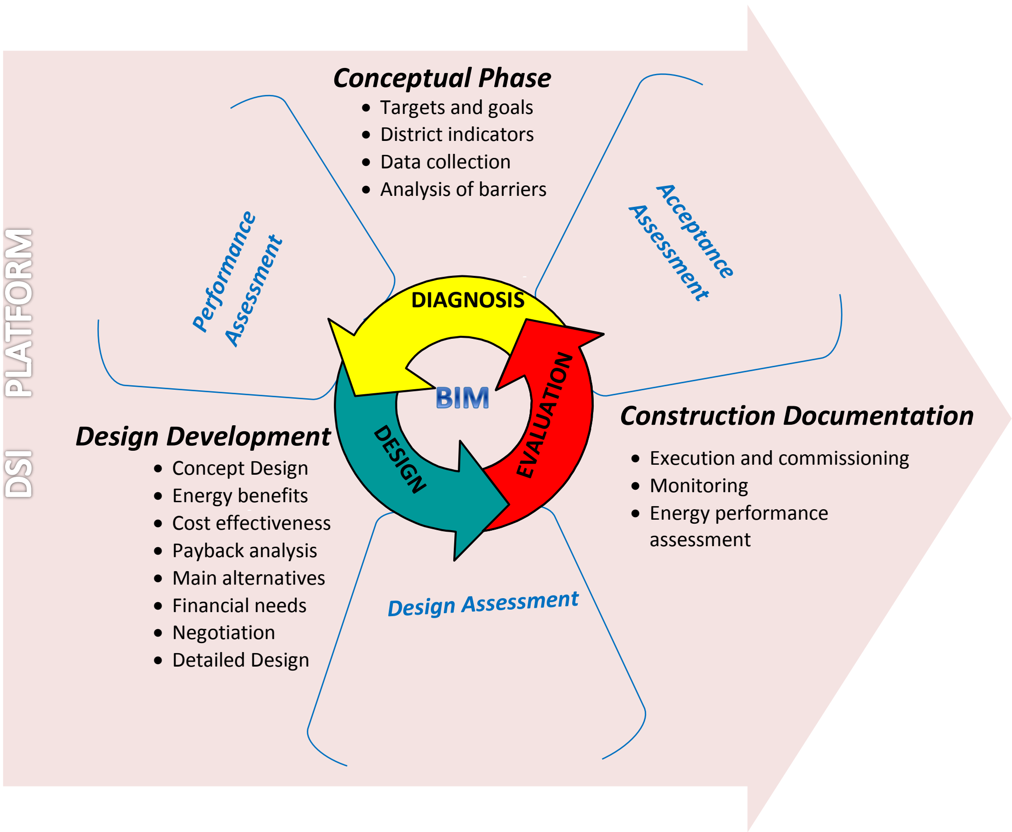


Figure 4.2: Technical level of BIM structure

Based on the diagnosis phase evaluations done, possible barriers that might be faced during the process must be identified.

DSI Platform

For the BIM platform, the data collection is the most critical stage. It creates existing conditions as it is built. After that, primary simulations can be performed based on all this information.

In the design phase, the concept design will be initiated according to the aims of the project and investigation stage conclusions. Making decisions about the latest applications to be conducted in the field constitutes the objective of this stage. Detailed design is going to be completed according to the selection of the most suitable option. The starting point is to sum up the results of the previous phase. When areas of activities are clear, the integration of technologies in the base district model will start. There are different possibilities to integrate technologies, so in order to analyse them energy simulations of different combinations will be carried out.

In this phase, the real situation of the district without any intervention should be described. After that, potential technologies that could be implemented in the demo site are defined. Then, different combination of alternative technologies will be analysed for the purpose of getting the best design, the final concept design.

Data analysis gives evidence to generate a theoretical model for costs in the building design process. This model applies to architecture and engineering teams that are heavily involved in the project delivery. From the cost point of view, the components of a design project may be divided into the following categories:

- Design costs
- Communication costs
- Management costs
- Profits and discretionary funds

When the conceptual design has been chosen in a workshop where all roles that are involved in the phase will be represented, more additional information will be created and the negotiation phase can start. If this phase is resolved positively and the conceptual design is accepted, the focus will pass to the detailed design phase.

Explanation of the elaborate design parameters and the all of the district are involved in the detailed design stage. Matching the duties with the aims, a new type of concept design will be realized when the proposing/agreement stage is completed. This is known as the detailed design.

Compatibility with the design fundamentals on which the concept design was established, solving undecided matters from concept design, involving doubts and demands of partners, realizing risk management, achieving aims related to energy, environment and indoor quality.

In order to use the BIM toolset the detailed design will be made more particular, at the same time combined energy simulations are going to be enhanced. A report of the detailed design process will be elaborated, including all the engineering and construction documents, according with the information standards established in the BIM platform.

During the technical level, execution and commissioning should be assured in order to proceed to the next step which is monitoring and energy performance assessment. After all, acceptance assessment can be done for the final evaluation of the project.

BIM Tools

In this section, project phases are identified according to the insulation material application. Detailed information can be seen on the table below.

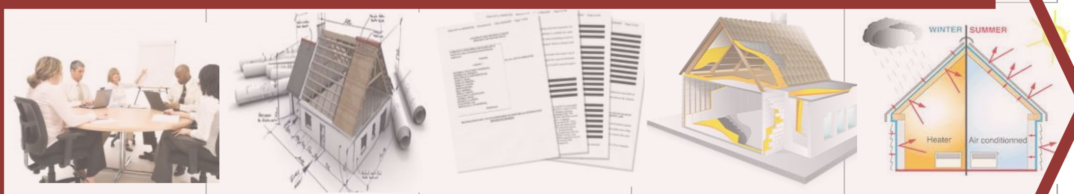
	Conceptualization	Design	Implementation	Construction	Own/Operate
PROJECT PHASE	Integrated project delivery with BIM forms a study guide for the following stages of the insulation application. Conceptualization provides continuity of the progress and enables budget planning from the earliest stage.	Cooperation between stakeholders that are involved during the insulation design is important for that stage. Project quality can be easily maximized and risks are minimized by their co-decisions.	Preparation of precise virtual models about insulation application helps for minimizing document uncertainty and implementation problems during documantation.	During the construction process, efficient use of materials can be satisfied and waste production can be decreased due to the early planning and design done by related stakeholders. No need about changing operation plan or no additional expenses are required.	Building users as they are owners and tenants can live in their buildings with high thermal standards as it is mentioned before by the previous steps. With the calculated thickness, targeted thermal comfort range can be satisfied.
					
STAKEHOLDERS	Architect	Owner	Architect	Workman	Owner
	Contractor	Architect	Engineer	Engineer	Tenant
	Engineer	Energy performance analyser	Contractor	Architect	
				Contractor	

Table 4.1: Project phases and implementation of insulation material

Different types of software can be used in the different phases and by different stakeholders. Examples of BIM tools are Revit, ArchiCAD, Allplan or Vectorworks, among others. Revit and ArchiCAD have some interesting energy analysis capabilities and are widely used in Architecture, Engineering and Construction industry, reason why both tools are holding an important market position. Also, both tools provide a user-friendly interface, well organized according to workflow and they are easy to learn.

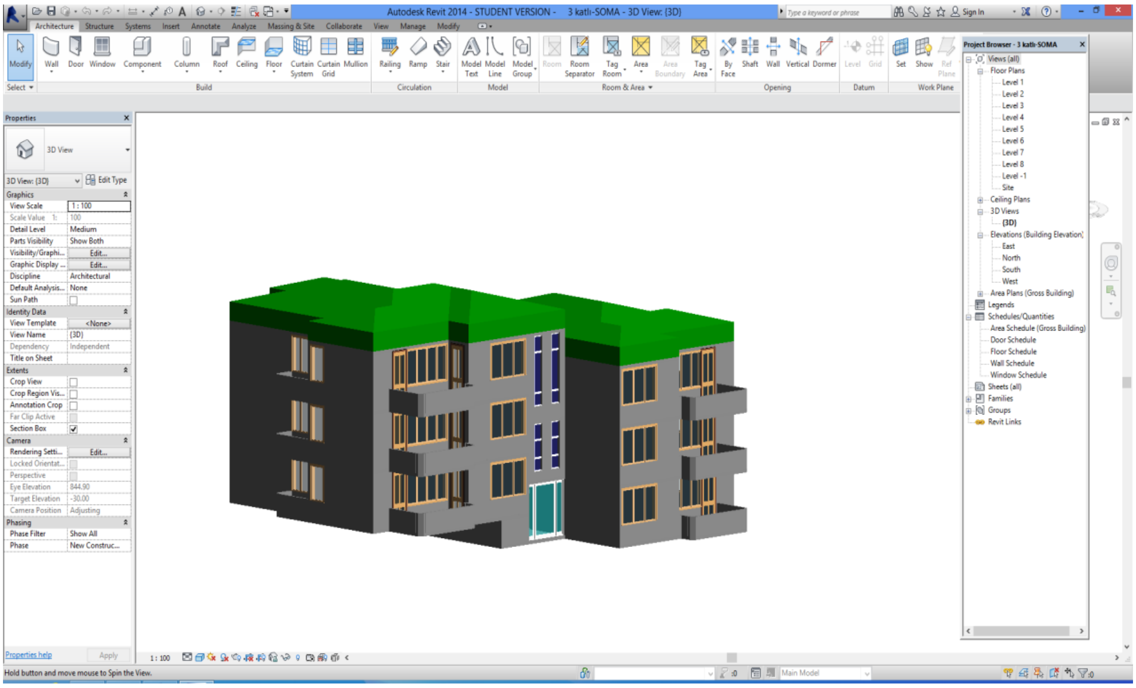


Figure 4.3: BIM software interface’s screenshot

Most applicable building thermal simulation tools

In this deliverable, certain selected BIM tools are reviewed based on insulation application in order to identify thermal simulation software and compare different tool opportunities which can be integrated to thermal analysis. Input and output data of tools as DPV, Design Builder, Ecotect, eQUEST, EnergyPlus, EcoDesigner, ESP-r, Green Building Studio, Lesosai, IDA ICE, IES VE, TRACE700, TRNSYS and Riuska are identified in detailed. Required geometry imports for related applications are explained for each tool in the table below.

Tool	Application	Input data	Output data	BIM based geometry import
DPV (Design Performance Viewer)	Environmental design, *thermal design and analysis*, heating and cooling loads, energy cost, Exergy/CO2, life cycle assessment, scheduling.	CAD-BIM, Revit	-	The building model is directly built in the CAD-BIM environment.

Tool	Application	Input data	Output data	BIM based geometry import
DesignBuilder	Environmental design, 3D Model (3D Design), *thermal design and analysis*, heating and cooling loads, natural and artificial lighting, Internal air, mean radiant and operative temperatures, humidity, CO2 emissions, solar shading, heat transmission, solar shading, scheduling.	gbXML, .dxf, .pdf, .bmp, .jpg	CAD: AutoCAD, Microstation, SketchUp using 3-D dxf, .epw, .csv, .tmy, .tmy2	Provides interoperability with BIM models through its .gbXML import capability.
Ecotect	Environmental design, 3D Model (3D Design), *thermal design and analysis*, heating and cooling loads, Validation; Solar control, overshadowing, prevailing, winds & air Flow, natural and artificial lighting, life cycle assessment, life cycle costing, scheduling, geometric and statistical acoustic analysis.	.dwg, .ifc,gbXML, .obj, 3DS, .xml, ASCII, *etc*.	Metafiles, Bitmaps or animations. RADIANCE, POV Ray, VRML, AutoCAD dxf, EnergyPlus, ESP-r, ASCII Mod files, XML, *etc*.	Imports CAD-BIM models from most CAD software
eQUEST	Energy performance, simulation, energy use analysis, conceptual design performance analysis, 3D Model (3D Design), *thermal design and analysis*, heating and cooling loads, Solar control, overshadowing, Lighting system, life cycle assessment, life cycle costing, Scheduling.	gbXML, .dwg, dxf	dxf, gbXML, .xls	Support gbXML format
EnergyPlus	Energy Simulation, *thermal design and analysis*, Heating and cooling loads, Validation; Solar control, Overshadowing, Natural and artificial lighting, Life cycle assessment, Life cycle costing, Scheduling.	ifc, gbXML, text	ASCII	.ifc compatible. (BIM Application)
EcoDesigner	Energy balance evaluation, CO2, overshadowing, *heating*, *cooling*, lighting, water use, Life cycle costing, Scheduling, prime energy usage (gas, energy, electricity, etc.)	gbXML	gbXML, .pdf	Provides another dimension in the BIM environment for the architect in shaping his design

Tool	Application	Input data	Output data	BIM based geometry import
ESP-r	Environmental Design, 3D Design, *thermal design and analysis*, heating and cooling loads, Solar control, lighting, natural ventilation, combined heat and electrical power generation and photovoltaic facades, acoustic analysis, life cycle and environmental impacts assessments.	XML	XML, csv, VRML	no
Green Building Studio	Environmental Design, *thermal analysis*, annual energy consumption (electric and gas), Carbon emissions, day lighting, water usage and cost, Life cycle costing, natural ventilation.	gbXMLenabled BIM or 3D-CAD	gbXML, VRML	Supports gbXML format and has easy interoperability with BIM Application
Lesosai	*thermal design and analysis*, Heating and cooling loads, Solar control, CO2, natural and artificial lighting, life cycle assessment, life cycle costing, Scheduling.	gbXML, .nbdm, .skp	.xls, .xml, .pdf, .bld, .txt files	Supports gbXML format and has easy interoperability with BIM Application
IDA ICE	Environmental design, 3D Model (3D Design), *thermal design and analysis*, heating and cooling, Solar and shading, surface transmissions, air leakage, cold bridges and furniture, lighting, Air CO2 and moisture levels, Energy costing.	.ifc, .dxf, .dwf, .3ds, .cgm, .cmx, .dgn	.html, .doc, .xls, .jpeg, .jpg, .png, .tiff, .bmp	.ifc compatible. (BIM Application)
IES VE	*Thermal design and analysis*, heating and cooling loads, CO2, Validation; Solar, Shading, Lighting, Airflow, Life cycle costing, Scheduling, fire evacuation.	gbXML, .dxf, .dwg	.ve	Supports gbXML format and has easy interoperability with BIM Application
TRACE 700	Environmental design, 3D Model (3D Design), *thermal design and analysis*, heating and cooling, life cycle costing, plants system.	gbXML	.pdf, .rtf, .txt, .doc, .xls	Supports gbXML format and has easy interoperability with BIM Application

Tool	Application	Input data	Output data	BIM based geometry import
TRNSYS	Environmental design, 3D Model (3D Design), *thermal design and analysis*, heating and cooling loads, Solar control, overshadowing, prevailing winds & air Flow, electrical, photovoltaic, hydrogen systems, Life cycle costing.	.skp, ASCII, .xml	ASCII (Simulation Studio Tool : HTML, C++)	no
Riuska	Environmental design, 3D Model, *thermal design and analysis*, heating and cooling loads, validation; Solar control, overshadowing, lighting, life cycle assessment, life cycle costing, scheduling.	.ifc	.ifc	.ifc compatible. (BIM Application)

Table 4.2: Thermal tools can be applicable in BIM platforms (33)

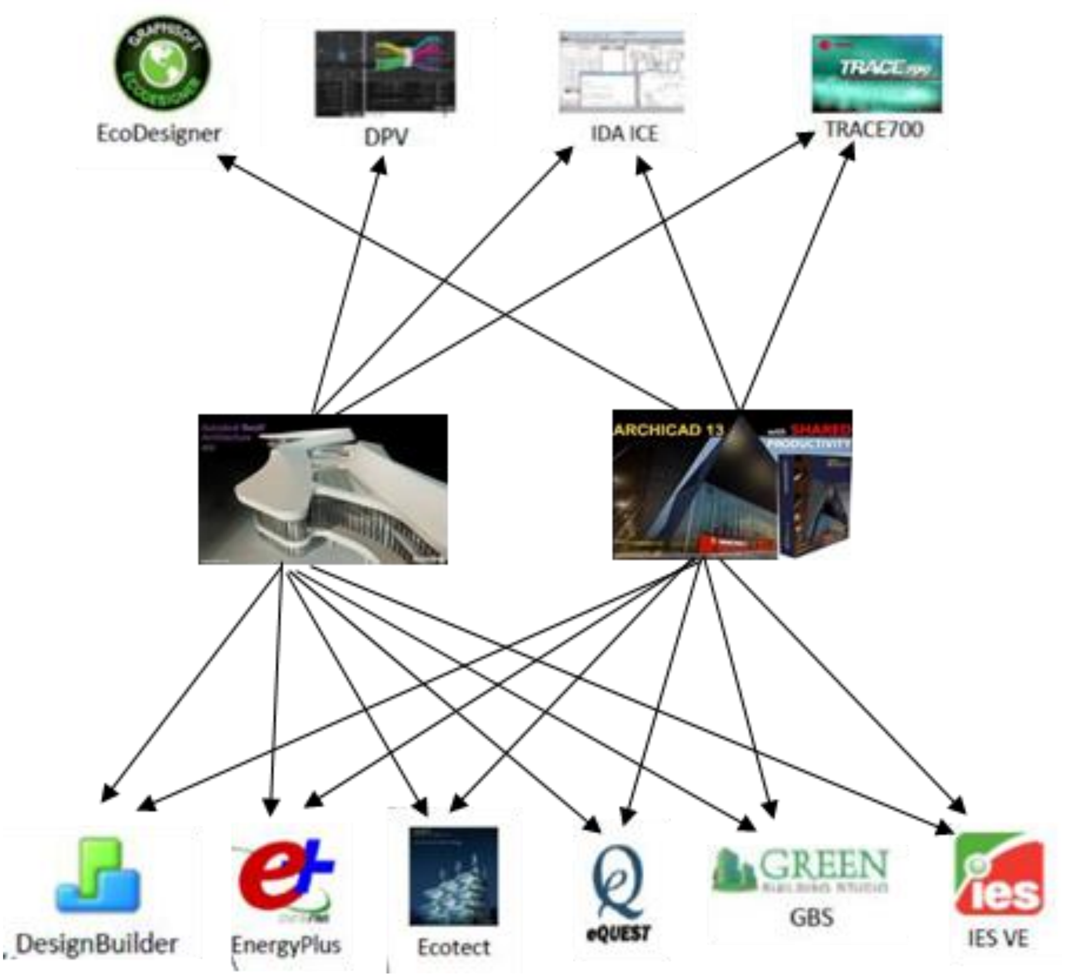


Figure 4.4: Most applicable tools for building thermal simulation

The BIM methodology has created a new way of working, different from the traditional method. This is changing the workflows and it is allowing dynamic analysis. The design process using BIM is iterative, that is, the analyses can be performed at several times within the Project lifecycle since making changes in the BIM model are less time-consuming than making them in the approach. This supports decisions-making process and better designs and allows the design team to perform what-if scenarios to compare and balance cost, quality, and sustainability. Thermal simulation tools need two kinds of inputs: geometry and data.

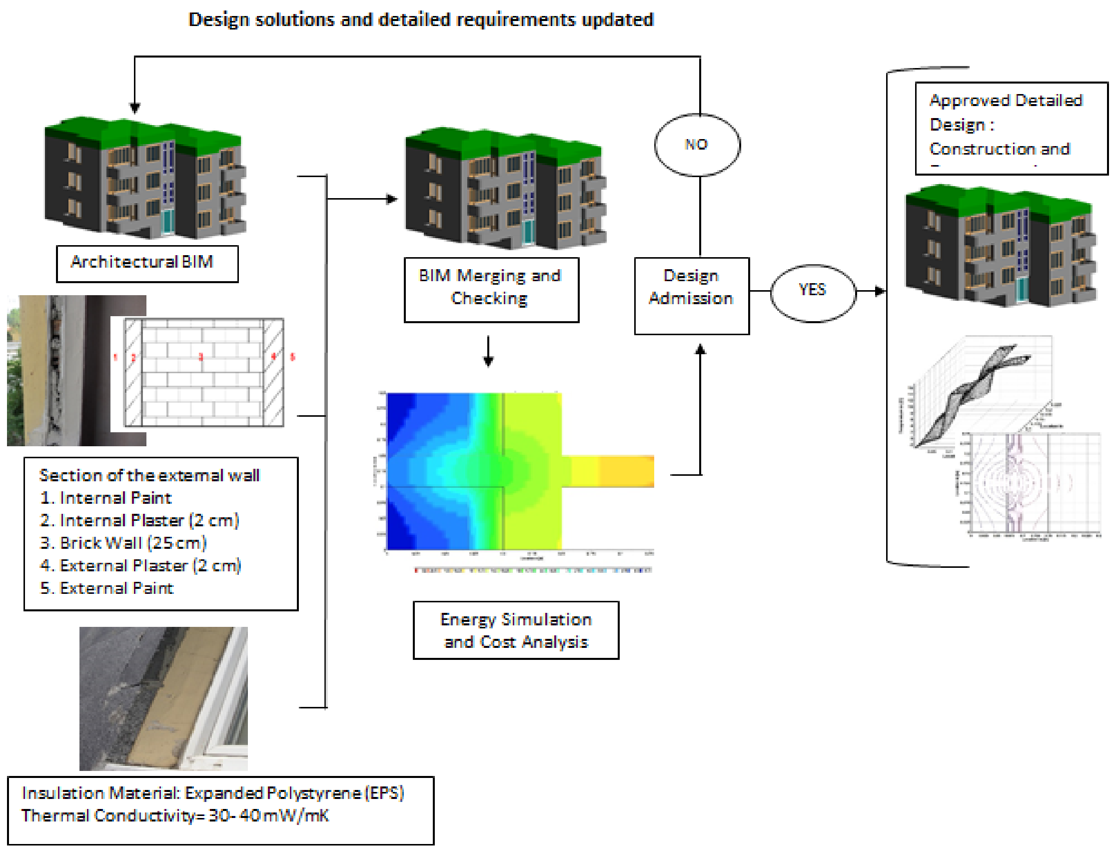


Figure 4.5: BIM methodology applied to insulation thickness definition

The expected benefits or savings for BIM application in the case of insulation

The Stanford University Centre for Integrated Facilities Engineering (CIFE) figures the benefits based on 32 major projects using BIM such as:

- Up to 40% elimination of unbudgeted change
- Cost estimation accuracy within 3%
- Up to 80% reduction in time taken to generate a cost estimate
- A savings of up to 10% of the contract value through clash detections
- Up to 7% reduction in project time

Revit and eQuest BIM tools are used respectively for modelling the building and determining the energy performance of the building. After that, taking into account the results of the simulations, economic evaluation of this implementation is done. Within the BIM technology, coordination of all aspects of the work from the very beginning is a key factor. Therefore, it enables innovation involving at all stages of project. BIM keeps all data related to the building as smart objects, thus all information can be controlled, checked and changed instantly. Moreover, it leads to faster and more effective processes. In BIM, the model can be used to demonstrate the entire building life-cycle. Accordingly, better production quality and customer service is obtained.

The use of BIM in architecture and engineering tasks has a direct effect of reducing the communication costs. Primary components of communication costs include the cost of producing drawings, the cost of holding meetings or participating in conversations, and the cost of conveying information electronically or in paper documents. Savings in design costs are likely to be reinvested into design and thus are difficult to distinguish. Stakeholders confirmed that time and cost savings from communication that resulted from BIM adoption increased the amount of discretionary funds available that can either be taken as profit or diverted to improve design quality. The figure below shows a design cost model for architecture and engineering teams. (34)

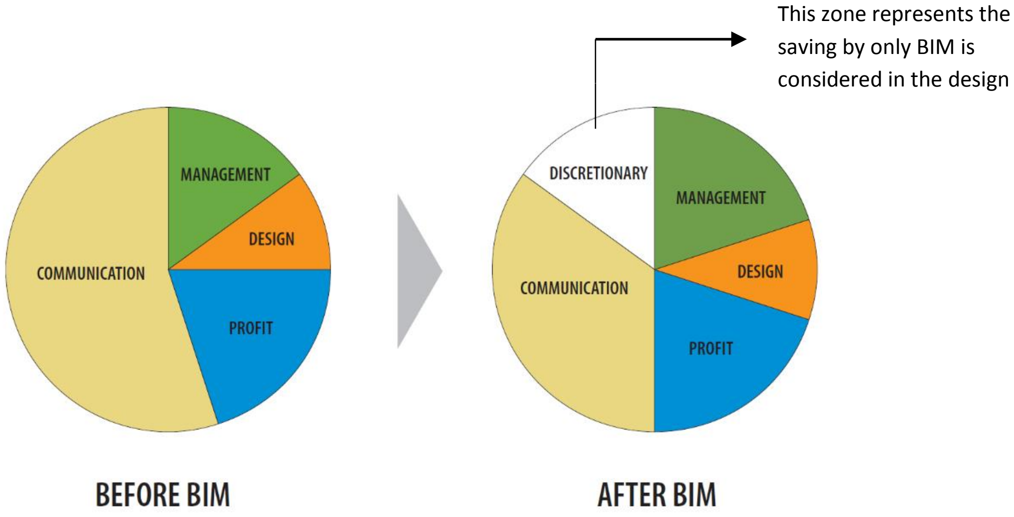


Figure 4.6: Design cost model before and after BIM

The specific results of CITyFiED project related to savings from BIM application in each demo site will be defined after the project results. The following document is prepared for each demo site, accordingly.

MANAGEMENT LEVEL	Demolition, Refurbishment	Insulation application
	Construction Management	Insulation with EPS – Expanded Polistyrene Thermal conductivity values for EPS are between 30 and 40 mW/(mK)
	Stakeholders	Architects, engineers and energy performance analysers.
	User Profile	Residents (all ages include elderly to kids)
	Laws and Regulations	TS 825 – TS 7316 EN 13163
	Comfort Profile Standards	TS EN 15251
TECHNICAL LEVEL	CAD Software	AutoCAD
	VRML (Virtual Reality Modelling Language)	Revit Architecture
	Simulations	eQuest
	Specific Technics	Radiant Heating Panels
	Energy Saving Value	Nearly up to %50

Table 4.3: BIM level application

4.2 Optimum insulation thickness for building walls with respect to heating degree-days for conventional systems

The proper design and selection of a building envelope and its components are efficient means to reduce the space heating-cooling loads. As such, thermal insulation is one of the most valuable tools in achieving energy conservation in buildings. (35)

Determining both type of thermal insulation material and the economic thickness of the material used in the building envelope are the main subjects of many engineering investigations. These studies help to reduce building energy demand (annual energy requirements for heating and cooling).

The concept of economic thermal insulation thickness considers the initial cost of the insulation system plus the ongoing value of energy savings over the expected service lifetime of the insulation. The optimum economic thickness is the value that provides the minimum total life-cycle cost, as illustrated in Figure 4.7, Optimum insulation thickness. The thickness is a function of the following: the building type, function, shape, orientation, construction materials, climatic conditions, insulation material and cost, energy type and cost, and the type and efficiency of air-conditioning system. (2) As the insulation thickness in a wall increases, the heating and cooling transmission loads for a building decrease. The transmission loads are used as the input data for an economic model to determine the variation in the cost of the insulation plus the present value of energy consumption, considered lost energy, over the lifetime of the building with such insulation.

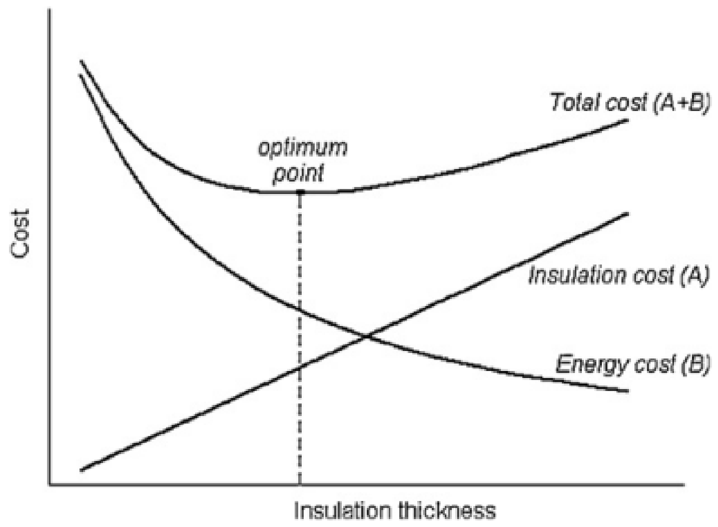


Figure 4.7: Optimum insulation thickness

In most studies, the optimum insulation thickness computations were performed based mainly on the heating and cooling loads and other parameters such as the costs of the insulation material and energy efficiencies of the heating and cooling systems, the lifetime and the current inflation and discount rates. For that reason, the annual heating and cooling energy requirements of a building were the main inputs required to analyse the optimum insulation thickness. Most studies estimate the heating and cooling energy requirements by the degree-time concept (degree-day, DD or degree-hour, DH), which is one of the simplest methods applied under static conditions. (36) On the other hand, only a limited number of analytical techniques were applied to analyse the transient behaviour of multilayer building envelopes. (37)

Thermal insulation is known to play a critical role in saving energy by reducing the rate of heat transfer. Determining the amount of insulation material required in walls is a key factor. Numerous studies estimated the optimum thickness of thermal insulation used in external walls for different climate conditions. (38) Most studies dealing with optimum insulation thickness were based on either heating loads or cooling loads while some works considered both annual heating and cooling loads. (39)

As mentioned previously, determining the heating and cooling transmission loads of buildings is an important issue for optimizing the insulation thickness. To estimate the amount of energy required for heating or cooling, one of the commonly used methods is the degree-days or degree-hours method, calculated as the difference between the base temperature and the mean outdoor air temperature. Using this method requires little data and provides adequate results for simple systems and applications.

4.2.1 Heating degree-days

One of the commonly used methods to estimate the amount of energy required for heating and cooling is the degree-days or degree-hours method, calculated as the difference between the base temperature and the mean outdoor air temperature, the method is used by many authors. Using this method requires little data and provides adequate results for simple systems and applications.

The cooling and heating degree-days method is the most basic and most efficient way to calculate the heat transfer in the walls, and assumes that the energy requirement is proportional to the difference between outdoor temperature and indoor base temperature.

The total number of annual heating (HDD) and cooling degree-days (CDD) is calculated by;

$$HDD = \sum_{days} (T_b - T_0)^+$$ Equation 4.1

$$CDD = \sum_{days} (T_0 - T_b)^+$$ Equation 4.2

where T_b is the base temperature and T_o is the daily mean outdoor air temperature. The plus sign above the parentheses indicates that only positive values are to be counted. The heating and cooling degree-hours can be calculated in a similar manner with the hourly instead of the daily data.

4.2.2 Yearly heat loss from the buildings

The heat losses in buildings generally occur through external walls, windows, ceiling, floors and air infiltration. The heat loss from windows due to the infiltration is not taken into account since the insulation does not affect that heat loss. On the other hand, in these calculations only the heat loss from external walls is considered. Heat loss from per unit area of external wall is;

$$q = U * (T_b - T_o)$$ Equation 4.3

where U-value is the overall heat transfer coefficient.

The annual heat loss per unit area can be obtained from;

$$q_A = 86400 * DD * U$$ Equation 4.4

Annual energy requirement;

$$E_A = \frac{86400 * q_A * DD}{\eta}$$ Equation 4.5

4.2.3 Optimum insulation thickness and energy savings over the lifetime

This report aims to explain optimum insulation thickness for each demo site. Because of different type of fuels, U-values and costs valid for demo sites, it is needed to calculate with separate parameters. In the table below, the available parameters for each demo site are given.

Parameter		Value		
Explanation		**Valladolid**	**Soma**	**Lund**
HDD	Heating degree day	3,121 (20°C)	1,783 (18°C)	3,277 (17°C)
Fuel type		Biomass (Wood Chips)	Lignite	Biogass
η (%)	Fuel efficiency	0.80	0.65	0.8
C_f (€/kWh)	Fuel price	0.25	0.092	0.09
LHV (J/m^3)	Lower Heating Value	6.00E+06	2.30E+07	3.97E+07
Insulation material		EPS	EPS	Mineral wool
k (W/mK)	Conductivity	0.037	0.04	0.036
C_i (€/m^3)	Insulation material cost	40	70	60-90
ρ (kg/m^3)	Density	15-20	20	20-50
General information				
i (%)	Interest rate	0.3	0.8	0.3
g (%)	Inflation rate	4	0.749	1.1
N (year)	Lifetime of the system	20	20	20
R_{wt} (m^{2}K/W)	Total wall thermal resistance	0.7353	0.56179	2.5

Table 4.4: Parameters used in each demo site

After the evaluation the yearly heat demands to calculate cost accounting, the Present-Worth Factor (PWF) will be used.

If $i < g$

$$r = \frac{(i-g)}{(1+g)} \qquad \text{Equation 4.6}$$

If $i > g$

$$r = \frac{(g-i)}{(1+i)} \qquad \text{Equation 4.7}$$

$$PWF = \frac{(1+r)^N - 1}{r * (1+r)^N}$$ Equation 4.8

Total cost formula

$$C_T = \frac{86400 * DD * PWF * C_f}{\left(R_{wt} + \frac{x}{k}\right) * H_U * \eta} + C_i * x_{opt}$$ Equation 4.9

$$x_{opt} = \left(\frac{86400 * DD * C_f * PWF * k}{H_U * C_i * \eta}\right)^{\frac{1}{2}} - k * R_{wt}$$ Equation 4.10

4.2.4 Building information modelling

The specific results of CITyFiED project related to the application of BIM will be defined after the project results for each demo site. The following table is prepared for each demo site accordingly.

MANAGEMENT LEVEL	Demolition, Refurbishment	Insulation application
	Construction Management	Insulation with EPS – Expanded Polistyrene with thermal conductivity value of 0.037 W/mK
	Stakeholders	Architects, engineers and energy performance analysers
	User Profile	Residents (all ages include elderly to kids)
	Laws and Regulations	CTE - DB HE, Código Técnico de la Edificación Documento Básico Ahorro de Energía (Spanish Technical Building Code)
	Comfort Profile Standards	CTE - DB HE, Código Técnico de la Edificación Documento Básico Ahorro de Energía (Spanish Technical Building Code)
TECHNICAL LEVEL	CAD Software	AutoCAD
	VRML (Virtual Reality Modelling Language)	Revit Architecture
	Simulations	DesignBuilder
	Specific Technics	-
	Energy Saving Value	39.7 %

Table 4.5: Spanish demo site, Laguna de Duero - Conventional System

In the Spanish demo site, the retrofitting intervention follows the criteria stablished in CTE (Spanish Technical Building Code) and the energy performance simulation have been done with DesignBuilder software. The solution chosen is an insulation layer of EPS, 8 cm thickness, with a thermal conductivity value of 0.037 W/mK.

MANAGEMENT LEVEL	Demolition, Refurbishment	Insulation application
	Construction Management	Insulation with EPS –Expanded Polistyrene with thermal conductivity value of 0.040 W/mK
	Stakeholders	Architects, engineers (mechanicals, electronicals, civil etc.) and energy performance analyzers
	User Profile	Residents (all ages include elderly to kids)
	Laws and Regulations	TS 825 – TS 7316 EN 13163 (Turkish Building Standards)
	Comfort Profile Standards	TS EN 15251
TECHNICAL LEVEL	CAD Software	AutoCAD
	VRML (Virtual Reality Modelling Language)	Revit Architecture
	Simulations	eQuest
	Specific Technics	-
	Energy Saving Value	48%

Table 4.6: Turkish demo site, Soma - Conventional System

Criteria for insulation are selected according to summer and winter conditions of the demo site. Moreover, certain standards are given for each country to develop a suitable insulation strategy. TS EN (Turkish Building Standards) is considered for Turkish demo site in Soma. As a result of required data collection, insulation material properties and specific design targets have to be set. This targets save energy up to 50%. For the total district 48% energy saving will be achieved in Soma.

Adding insulation to the external walls is one of the applicable potential technologies and after all optimization studies for insulation thickness, the design team (including architects, mechanical engineers and energy analysers) decided to implement expanded polystyrene (EPS) foam in Soma demo site. The thickness of the EPS foam is 5 cm with a thermal conductivity value of 0.040 W/mK.

MANAGEMENT LEVEL	Demolition, Refurbishment	Insulation application
	Construction Management	Insulation with mineral wool - 0.036 W/mK conductivity
	Stakeholders	Architects, engineers and energy performance analysers
	User Profile	Residents (all ages include elderly to kids)
	Laws and Regulations	BBR, Boverket's Building Regulations (Swedish building code)
	Comfort Profile Standards	Thermal comfort: BBR, Boverket's Building Regulations (Swedish building code)
TECHNICAL LEVEL	CAD Software	AutoCAD
	VRML (Virtual Reality Modelling Language)	3D/BIM modelling is not used
	Simulations	IDA ICE version 4.6.1
	Specific Technics	-
	Energy Saving Value	38%

Table 4.7: Swedish demo site, Lund - Conventional System

In the Swedish demo site, the retrofitting intervention follows the criteria stablished in BBR (Swedish building code) and the energy performance simulation have been done with IDA ICE software. The solution chosen is an insulation layer of mineral wool with a thermal conductivity value of 0.036 W/mK.

4.2.5 Life cycle cost analysis and Environmental impacts

LCCA

In the European Union, the building sector is responsible for a large consumption of energy (40%) and the corresponding CO_2 emissions. The insulation of buildings is an important strategy to reduce these energy consumption and CO_2 emissions, and therefore help achieving sustainability in buildings.

If buildings are properly designed and operated, relevant energy savings can be achieved. Hence, building designers have major importance in solving the energy problem, when adequate early design decisions are made concerning the selection and integration of building components. Thermal insulation materials have an important role and are a logical first step in order to reduce the energy required to keep an adequate interior temperature and therefore achieve energy efficiency (40).

The LCCA methodology is supposed to lead to the quantification of the environmental footprint for goods, services and processes, called products in the following. One of the attended objectives is to identify some main points allowing to do design choices permitting the diminution of the environmental impacts in one or several lifecycle steps. This approach is also called life cycle cost analysis, eco-balance or cradle-to-grave analysis (41).

Life cycle costing analysis for buildings generally model for total investment cost, and may include annual operation, maintenance and disposal costs.

The main use of buildings is to accommodate users and provide thermal comfort using mechanical heating and air conditioning systems when necessary. If the buildings are properly designed and operated, a considerable amount of energy can be saved. For each energy unit saved by a given measure of technology, resources can be saved, and the annual operating costs related with the production of that energy unit can be reduced or eliminated. Building designers have an important role because they can solve the energy problem if appropriate design decisions are made concerning the selection and integration of building components. Hence, concepts such as sustainability in buildings have been developed (40).

By considering the energy costs for heating and cooling, insulation materials and installation costs, the optimum insulation thicknesses have been determined on the basis of life-cycle cost analysis over lifetime of 20 years.

Environmental impacts

Environment impact assessment aims to link the release of substances and extractions of raw materials to their potential environmental damages. Impact pathways are environmentally linked processes, and state the fundamental chain of consequential effects derived from an extraction or emission.

Since the energy use in the building sector represents a relevant part of the total energy use in the world, as well as of greenhouse gas emissions, there is a demand to improve the energy efficiency of buildings. Concepts such as passive houses and zero emission buildings are being developed and, therefore, the use of thermal insulation materials highly contributes to improve the energy efficiency of a building. Various insulation materials with low thermal conductivity values have been and are being developed in order to achieve the highest possible thermal insulation resistance. Nonetheless, a very thick building envelope may not be feasible due to many reasons, including space issues with respect to economy, floor area, transport volumes, architectural restrictions and other limitations, availability of materials and existing building techniques.

In the EU, the building sector represents about 40% of the global energy consumption, and residential buildings are responsible for 63% of the energy consumption of the building sector. An improvement in building energy performance can constitute a relevant instrument to relieve EU energy import dependency and therefore comply with the Kyoto Protocol by reducing CO_2 emissions.

4.3 Optimum insulation thickness for low temperature systems

Low temperature systems are systems where heat generation occurs by the circulation of water or air. If 50% of heat transfer or more is by radiation, the surface is named radiant panel. These systems are characterized by the controlled surface temperature which is lower than 150 °C. Also these systems can work with fan-coil systems and renewable energy sources.

The fluid which is used for these low temperature systems is generally water. These systems can assemble to building wall, floor and ceiling.

With low temperature systems, people in the room do not directly feel whether the room is heated or cooled. If temperatures of the building surfaces are significantly different from ambient temperature, convection mechanism is forced to eliminate discomfort caused by extreme hot and extreme cold surfaces. Low temperature system panels fulfil this need.

Most of the building materials have high emissivity, so the heat that gains from radiant panels radiates again. Against the wavelengths diffused by transparent glazing, radiant panels are opaque, so a small portion of longer wavelength radiation passes to the outside. These positive features are the important factors for thermal comfort (42).

The working principle of low temperature heating systems can be described as follows. Heat or cold water supply from heat pump or other alternative energy source goes through plastic pipes located in the radiant panel. The heat transfer occurs on radiation plate over plastic pipes. If the thermal resistance between plastic pipes and radiation plate is low, thermal energy transfers more than conventional systems to plate then room. To prevent panel deformation, backfill material can be use between plastic pipe and radiation plate (43).

Insulation will be implemented in the façades of the buildings. At the same time, low temperature heating and cooling systems are developed and will be implemented in Soma demo site. For that matter, considering both façade insulation and panel insulation are important for life cycle cost analysis.

To calculate optimum thickness, it is important to investigate the heating capacity of the radiant heating panels.

Analytical study about calculation of heat capacity in the standard is not to match with our system.

$$q = B * a_T^{mT} * a_U * a_{WL} * a_K * \Delta T_H \qquad \text{Equation 4.11}$$

B parameter is different for every product. So, it is important to study the numerical and analytical analysis because standard which deals with the calculations about low temperature heating system is not clear enough for our system. So, in the following section, numerical and analytical studies are done to find out B value and heat fluxes.

4.3.1 Determining the heating capacity of radiant heating panels

This process is developed through the three following steps:

Numerical analysis

Before performing the optimum insulation thickness calculation, the heat flux losses between radiant panel and room, and radiant panel and ambient need to be calculated according to different insulation thickness.

In this section, two different paths are followed and they are compared with each other.

Panel geometry is modelled using Ansys Fluent 14.0. Heat fluxes calculated with specified boundary conditions.

In this study, the panel geometry design is unique. There are two different types in order to stablish a comparison between them. These are;

- Pipe distance : 100 mm
- Pipe distance : 150 mm

The characteristics analysed are the same for both models.

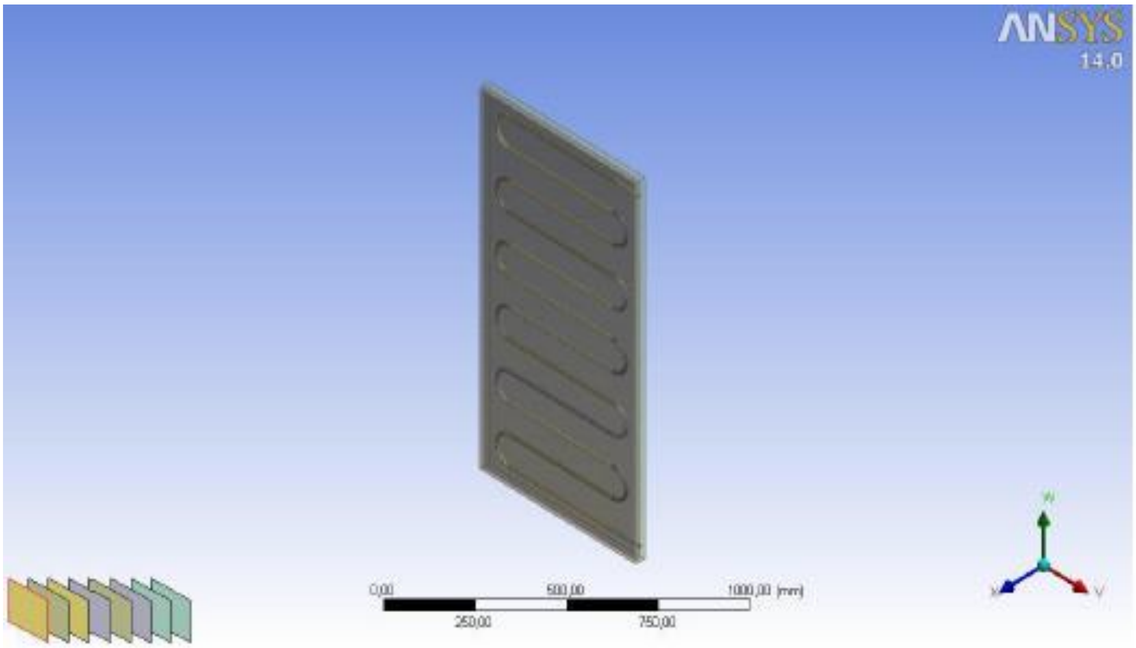


Figure 4.8: Panel geometry

<u>Mesh</u>

Although there are different panel geometries, mesh step is the same for both of them. The details of mesh step are as follows;

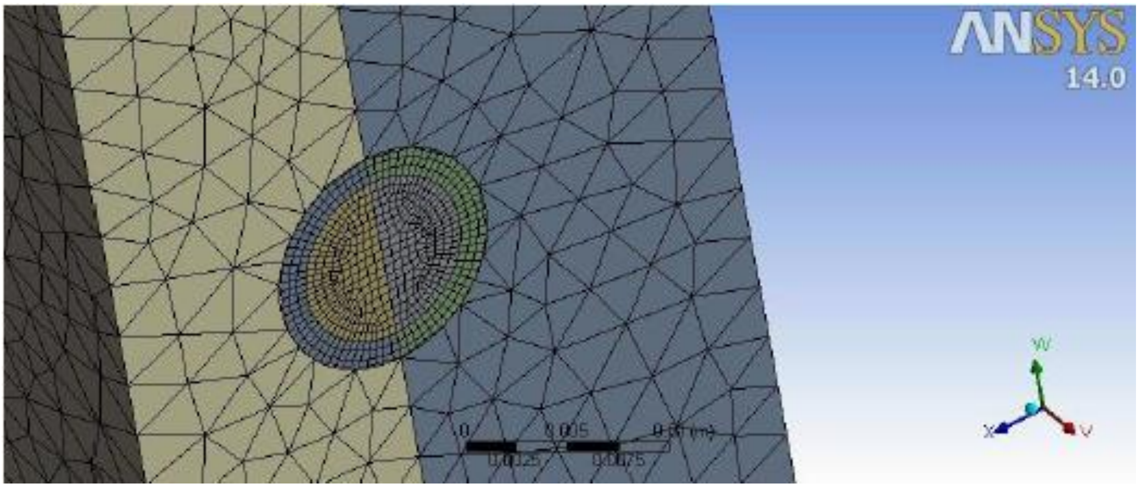


Figure 4.9: Mesh geometry in pipe area

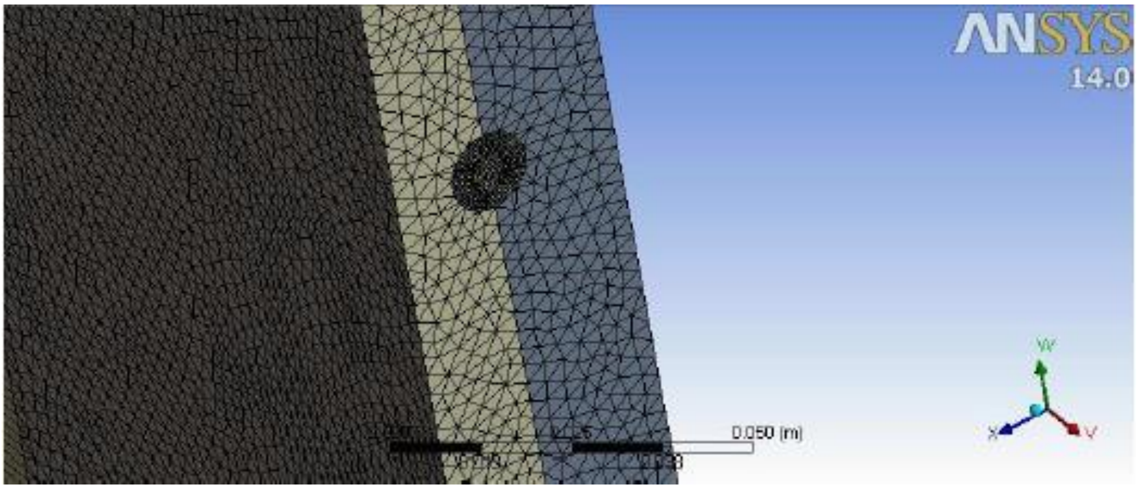


Figure 4.10: Mesh geometry

An important step of meshing is the “name selections” part. In this part, common surfaces of different geometries which need to share the same mesh data identify each other, so that the solution is ensured. If there is any mistake in this part, a solution can be impossible to achieve.

After the aforementioned steps, the “setup” part starts. In numerical analysis, setup is the most important part because the parameters are defined in that part.

In this study, numerical and analytical calculations are compared so that various parameters are considered. Thus, the same model is solved several times with using multiple parameters. In parallel with this situation, multiple different solutions are obtained. Materials and cell zone condition parts are specified.

The next step in programme consists on explaining the system’s boundary conditions. After monitors are specified, 1,000 iterations are given. And calculation is started. In the radiant heating panel analysis, optimization will be done by means of interface temperature.

Analytical analysis

The formulations which are in on TS EN 1264-2 standard are used to develop this part. Heat flux calculations are studied with respect to this standard. Type B that is the closest type for the system is selected to study.

Defining the total heat flux (W/m[2])

Total heat flux is defined as follows;

$$q = B * a_T^{mT} * a_U * a_{WL} * a_K * \Delta T_H$$ Equation 4.12

a_T is calculated from s_U/λ_E values;

s_U/λ_E	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.10	0.15	0.18
a_T	1.103	1.10	1.097	1.093	1.091	1.088	1.082	1.075	1.064	1.059

Table 4.8: Parameter values

s_U: Plaster thickness

λ_E: Conduction coefficient for plaster

$$a_U = \frac{\frac{1}{a}}{\frac{1}{a} + \frac{s_U}{\lambda_E}}$$ Equation 4.13

a_{WL} is a heat conduction factor with respect to K_{WL}. b_U is a value with respect to T.

$$K_{WL} = \frac{s_{WL} * \lambda_{WL} + b_U * s_U * \lambda_E}{0.125}$$ Equation 4.14

T	0.05	0.075	0.1	0.15	0.2	0.225	0.3	0.375	0.45
b_U	1	1	1	0.77	0.5	0.43	2.25	0.1	0

Table 4.9: Parameter values

$s_{WL} * \lambda_{WL}$: Products of heat diffusion thickness and heat transfer coefficient values

$s_U * \lambda_E$: Products of plaster plate thickness and heat conduction values

0.125: Constant number

K_{WL} value changes by pipe distance length, in accordance with a_{WL} value changes also. A Matlab code that calculates all these data has been developed.

- $K_{WL} = 0.8590$ for 0.1 m
- $K_{WL} = 0.8446$ for 0.15 m

By calculating a_{WL} values, iterations between K_{WL} values given in the below table is done.

K_{WL}	0.5	0.6	0.7	0.8	0.9	1.0	∞
T				a_{WL}			
0.05	0.995	0.998	1	1	1	1	1
0.075	0.979	0.984	0.99	0.995	0.998	1	1.01
0.1	0.963	0.972	0.98	0.988	0.995	1	1.02
0.15	0.924	0.945	0.96	0974	0.99	1	1.04
0.2	0.894	0.921	0.943	0.961	0.98	1	1.06
0.225	0.88	0.908	0.934	0.955	0.975	1	1.07
0.3	0.83	0.87	0.91	0.94	0.97	1	1.09
0.375	0.815	0.86	0.90	0.93	0.97	1	1.1
0.45	0.81	0.86	0.90	0.93	0.97	1	1.1

Table 4.10: a_{WL} values in accordance with K_{WL} and T

- a_{WL} = 0.9915 for 0.1 m
- a_{WL} = 0.982 for 0.15 m

a_K is calculated by the below table which depends on pipe distance

T	0.05	0.075	0.1	0.15	0.2	0.225	0.3	0.375	0.45
a_K	1	0.99	1	0.98	0.92	0.9	0.82	0.72	0.60

Table 4.11: a_K values depending on T

- $a_K = 0.98$ for 0.1 m
- $a_K = 0.95$ for 0.15 m

ΔT_H is logarithmic temperature difference. The formulation can be shown in below;

$$\Delta T_H = \frac{T_{pg} - T_{pç}}{\left[\dfrac{\ln\left(T_{pg} - T_o\right)}{T_{pç} - T_o}\right]} \; (K) \quad \text{Equation 4.15}$$

T_{pg} = Inlet water temperature for panel (K)
$T_{pç}$ = Outlet water temperature for panel (K)
T_o = Ambient temperature (K)

B value is variable from the panel geometry to panel component properties. TS EN 1264-2 formulation is given below.

$$\frac{1}{B} = \frac{1}{B_o} + \frac{1}{\pi}\prod(a_i^{mi})T$$ Equation 4.16

$$B_o = [\frac{1}{2\lambda_R} ln \frac{d_a}{d_a - 2s_R}]$$ Equation 4.17

λ_R = Conduction coefficient of the pipe which water is circulated inside (W/mK)
d_a = Outlet diameter (m)
s_R =Pipe wall thickness (m)

Instead of calculating B values from aforementioned formula, heat flux value obtained from numerical analysis is used to find B value in the below formula within TS EN 1264-2 standard;

$$q = B * \prod(a_i^{mi})\Delta\vartheta_H$$ Equation 4.18

$$\prod(a_i^{mi}) = a_T^{mT} * a_U * a_{WL} * a_K$$ Equation 4.19

- $\prod(a_i^{mi})$ =0.7263 for 0.1 m
- $\prod(a_i^{mi})$=0.6572 for 0.15 m

$\Delta\vartheta_H$ value changes with variable panel inlet water temperature. Iterations will be done with different inlet water temperature to find out B value. Average B value is given in the below table

T_{inlet}(K)	T_{outlet}(K)	T_{room}(K)	$\Delta_{difference}$	Q_{room}	a_i^{mi}	B
298	297.86	292	5.9322	29.654	0.726	6.882
300	299.82	292	7.9121	38.280	0.726	6.661
303	302.76	292	10.8826	51.228	0.726	6.481
305	304.72	292	12.8630	59.844	0.726	6.405
308	307.75	292	15.8776	69.900	0.726	6.061
310	309.62	292	17.8138	81.428	0.726	6.293
313	312.57	292	20.7842	94.377	0.726	6.212

Table 4.12: B values for 100 mm pipe distance panels

T_{inlet}(K)	T_{outlet}(K)	T_{room}(K)	$\Delta_{difference}$	Q_{room}	a_i^{mi}	B
298	297.88	292	5.9397	27.792	0.657	7.119
300	299.84	292	7.9197	35.762	0.657	6.871
303	302.79	292	10.8947	47.811	0.657	6.677
305	304.76	292	12.8796	55.808	0.657	6.593
308	307.7	292	15.8495	67.973	0.657	6.525
310	309.67	292	17.8345	76.120	0.657	6.494
313	312.62	292	20.8094	88.228	0.657	6.451

Table 4.13: B values for 150 mm pipe distance panels

- $B_{average} = 6.434$ for 0.1 m
- $B_{average} = 6.676$ for 0.15 m

Total generated heat flux is identified with the formulations of the standards by using the above B values.

Determination of heat flux losses to ambient

Heat flux generated with radiant heating panel is not 100% useful. There are some heat losses with respect to outside temperature. Heat loss, q_U;

$$q_U = \frac{1}{R_U}\left(R_o * q + (\vartheta_i - \vartheta_U)\right)$$ Equation 4.20

$(\vartheta_i - \vartheta_U)$: Temperature difference between interior and exterior environment

R_o: The side of panel which is next to room

R_U: The side of panel which is next to outside

q: Total heat flux in regard to TS EN 1264-2

Determination of the heat fluxes to room

Difference between defined total heat flux and heat flux losses is the heat fluxes entered the room.

$$q_i = q - q_U$$ Equation 4.21

Comparison of numerical and analytical results

Analytical and numerical data are compared with each other. As a result of this comparison the results obtained by two analysis methods were measured in terms of consistency. With this aim, some of the parameters kept constant. Thereby, parameters of the two methods are variable with each other to provide a better fit and adapt to all of the variable parameters.

Wall thickness and outlet temperature are constant in these calculations.

Numerical Results			Analytical Results		
Inlet Temperature (K)	Q_{out}(W/m^2)	Q_{room}(W/m^2)	Inlet Temperature (K)	Q_{out}(W/m^2)	Q_{room}(W/m^2)
300	8.091	30.189	300	10.285	26.744
303	9.034	42.194	303	11.573	39.350
305	9.662	50.183	305	12.433	47.754
308	10.700	59.200	308	13.721	60.360
310	11.234	70.194	310	14.581	68.764
313	12.177	82.200	313	15.869	81.372

Table 4.14: 100 mm distanced pipe geometry results depending on inlet temperature (35˚C)

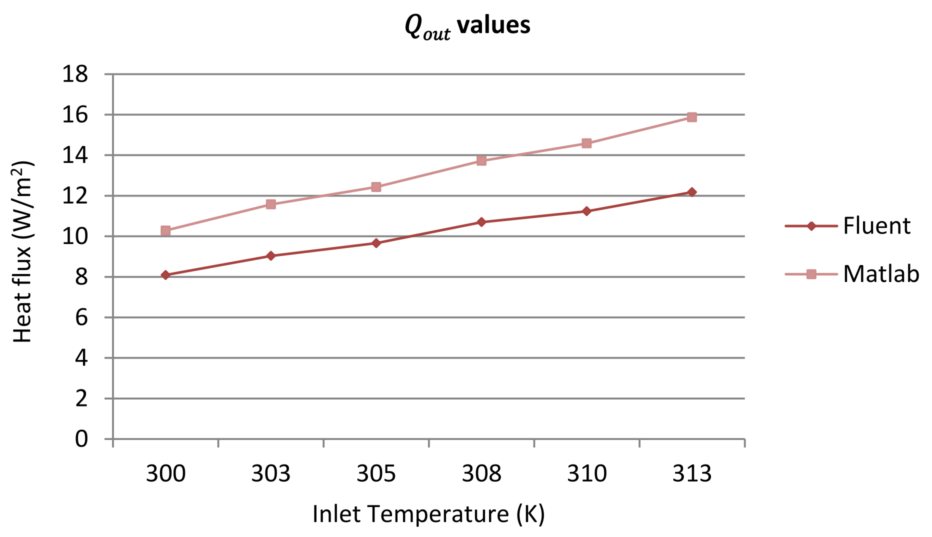


Figure 4.11: Comparison of Q_{out} values

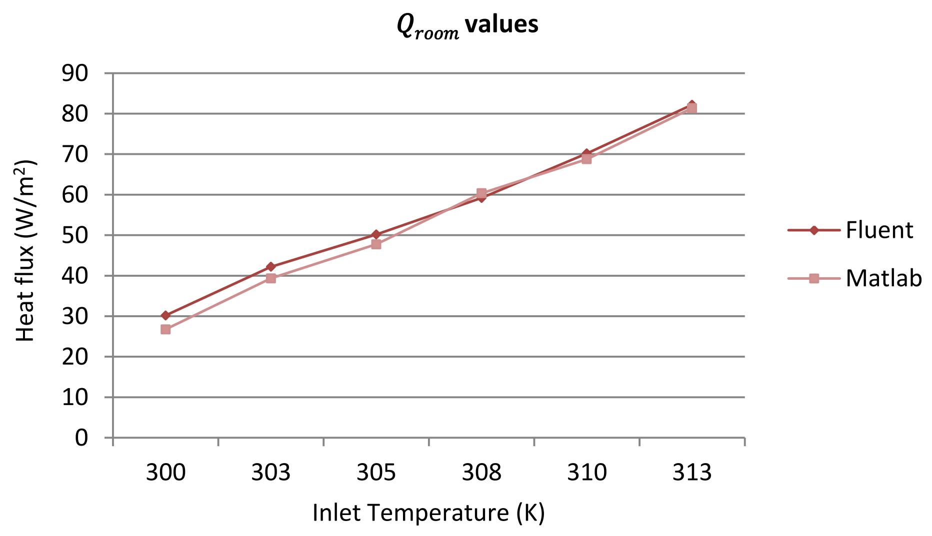


Figure 4.12: Comparison of Q_{room} values

Numerical	Analytical		Numerical	Analytical	
Q_{out}(W/m^2)	Q_{out}(W/m^2)	%	Q_{room}(W/m^2)	Q_{room}(W/m^2)	%
8.091	10.285	27.11	30.189	26.744	-11.41
9.043	11.573	28.10	42.194	39.350	-6.74
9.662	12.433	28.68	50.183	47.754	-4.83
10.700	13.721	28.24	59.200	60.360	1.96
11.234	14.580	29.79	70.194	68.764	-2.03
12.177	15.869	30.32	82.200	81.372	-1.01

Table 4.15: 100 mm distanced pipe geometry result errors depending on inlet temperature

Numerical Results			Analytical Results		
Inlet Temperature (K)	Q_{out}(W/m^2)	Q_{room}(W/m^2)	Inlet Temperature (K)	Q_{out}(W/m^2)	Q_{room}(W/m^2)
300	7.880	27.883	300	10.074	24.682
303	8.753	39.058	303	11.283	36.514
305	9.332	46.476	305	12.089	44.402
308	10.213	57.760	308	13.299	56.234
310	10.803	65.317	310	14.106	64.121
313	11.681	76.547	313	15.316	75.953

Table 4.16: 150 mm distanced pipe geometry results depending on inlet temperature

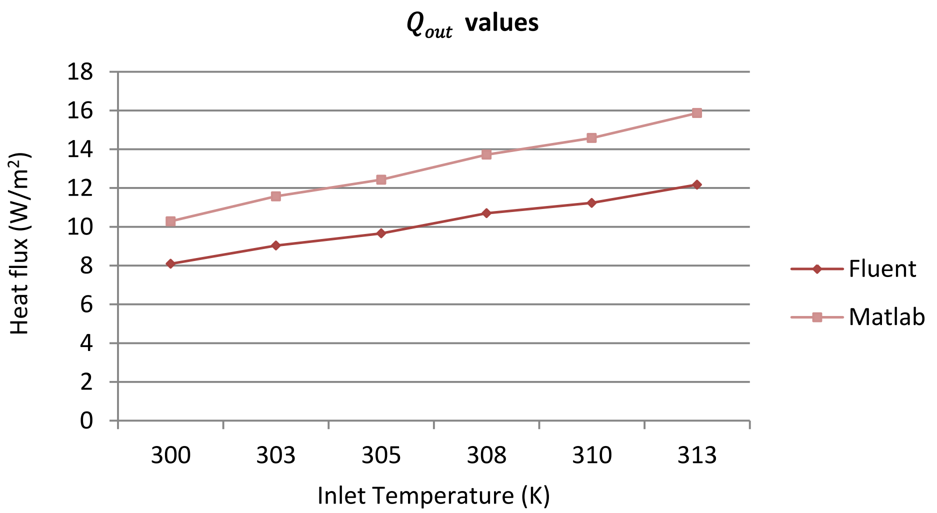


Figure 4.13: Comparison of Q_{out} values

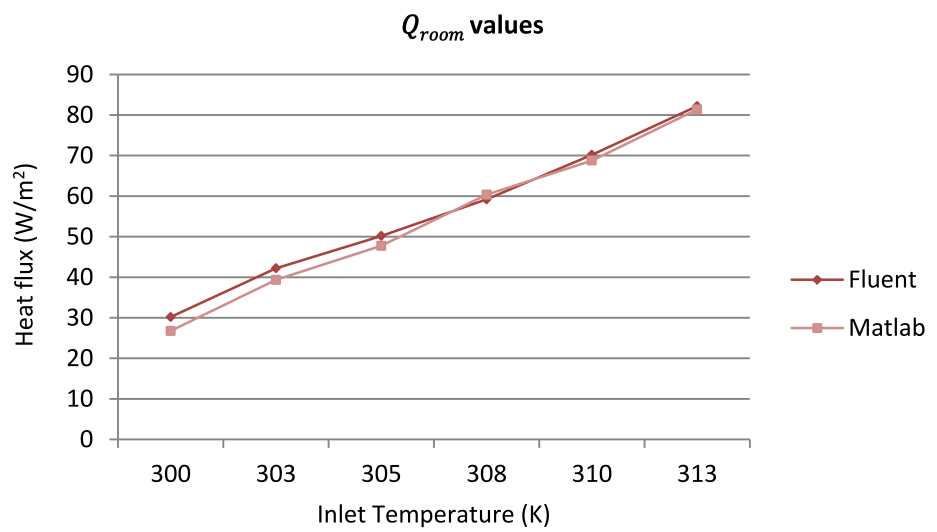


Figure 4.14: Comparison of Q_{room} values

Numerical	Analytical		Numerical	Analytical	
Q_{out}(W/m²)	Q_{out}(W/m²)	%	Q_{room}(W/m²)	Q_{room}(W/m²)	%
7.879	10.073	27.84	27.883	24.682	-11.48
8.753	11.283	28.91	39.058	36.514	-6.51
9.332	12.089	29.547	46.476	44.402	-4.46
10.213	13.299	30.222	57.760	56.234	-2.46
10.803	14.106	30.575	65.317	64.121	-1.83
11.681	15.316	31.116	76.547	75.953	-0.77

Table 4.17: 150 mm distanced pipe geometry result errors depending on inlet temperature

As a result, numerical and analytical values are quite similar. The heat flux loss from panel to room can be neglected. About heat flux loss from panel to ambient, analytical results provide higher values than numerical ones. In accordance with the variable parameters, the ratio between analytical and numerical data is less than or equal to 30.

4.3.2 Radiant heating panel configuration

Before the implementation of radiant heating system, heat loss and gains have been simulated with the energy simulation program in order to know the heat loss and gain of each volume in the buildings, both in heating and cooling season. After simulations, radiant ceiling heating and cooling panels are drawn by 2D CAD program. A sample of radiant ceiling pipe figures is shown below.

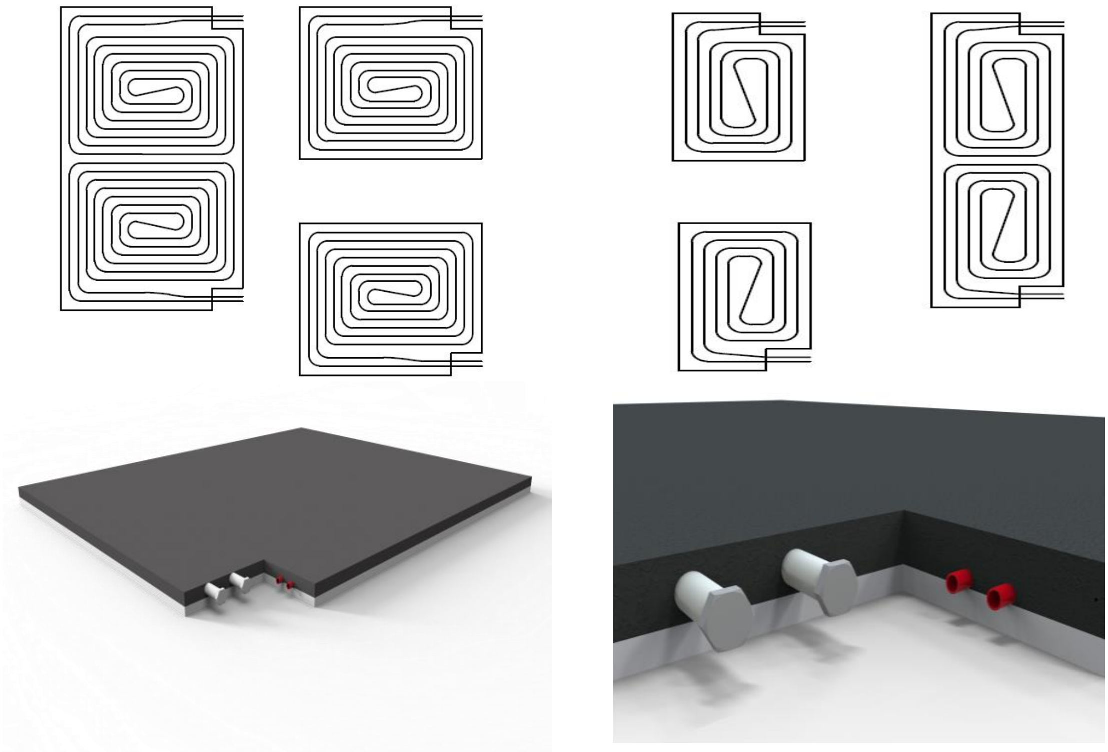


Figure 4.15: Panel geometries used in the demo-sites

Beside the radiant heating and cooling systems, control systems will be applied to the buildings. Thanks to the control systems, the radiant heating and cooling systems will work more efficiently than under current conditions and the energy saving will be increased by the hybrid system.

To provide convenience for production, pipe arrangements are switched between U shapes to spiral ones.

4.3.3 Layers of the radiant heating panel

Radiant heating panel consists of:

– Plaster

– Insulation

– PEX pipe

EPS is used as insulation material for radiant heating panel. Total thickness of radiant heating panel is 4 cm.

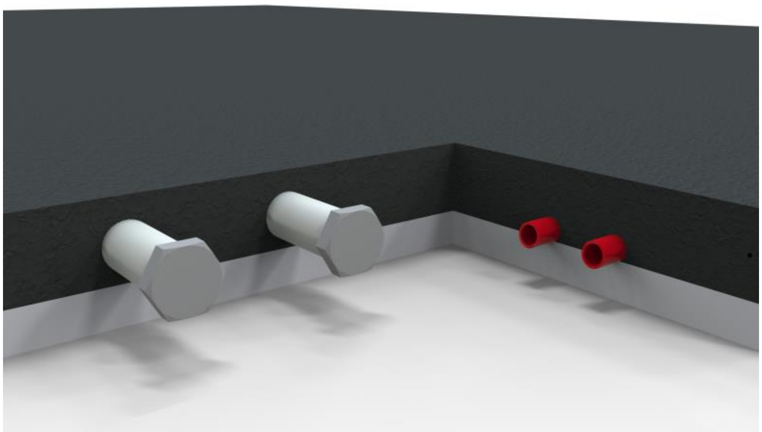


Figure 4.16: Radiant heating panel layers

4.3.4 Optimum insulation thickness and energy savings over the lifetime

To calculate optimum thickness calculations, parameters used for conventional systems are still valid. But there will be some new parameters such as;

C_{ii} : Inlet insulation material price (€/m^3)

C_{oi} : Outlet insulation material price (€/m^3)

All steps will be studied again. But, it has to be noted that, low temperature heating system calculations depend on various parameters, it can be calculated with MATLAB programme.

4.3.5 Building information modelling

The optimum insulation thickness for low temperature systems has been calculated for the Turkish demo site. Using this method, results are shown in the following table.

MANAGEMENT LEVEL	Demolition, Refurbishment	Insulation application
	Construction Management	Insulation with EPS –Expanded Polistyrene with thermal conductivity value of 0.040 W/mK
	Stakeholders	Architects, engineers and energy performance analyzers
	User Profile	Residents (all ages include elderly to kids)
	Laws and Regulations	TS 825 – TS 7316 EN 13163
	Comfort Profile Standards	TS EN 15251
TECHNICAL LEVEL	CAD Software	AutoCAD
	VRML (Virtual Reality Modelling Language)	Revit Architecture
	Simulations	eQuest
	Specific Technics	Radiant Heating Panels
	Energy Saving Value	Up to 42%

Table 4.18: Turkish demo site, Soma - Low Temperature System

4.3.6 Life cycle cost analysis and Environmental impacts

LCCA

Aforementioned explanations about energy savings with district heating system are valid for this section too. Additionally, with radiant heating system implementation, building qualifications are increased, for example with monitoring.

The payback period in the Turkish demo site is approximately one year, when considering the total annual energy requirements. Furthermore, BIM can be used in order to investigate the effectiveness of each parameter on the optimum insulation thickness and energy savings.

Environmental Impact

In the Turkish demo site, comparing with the existing condition, 121,310 kWh-lignite/year will be saved.

$$1\ kg\ Soma\ lignite = 6.38\ kWh\ energy$$ Equation 4.22

$$1\ Mt\ lignite = 0.35\ Mtce$$ Equation 4.23

For 20 year, the energy saved equals 133.09 Mtce[4] for the Turkish demo site. Some of the CITyFiED aims focus on environmental aspects, and the retrofitting uptake of low efficient building has an impact in terms of CO_2 emissions reduction and improves of the indoor air quality. Under these circumstances, both energy consumption and CO_2 emissions will be reduced in the three demo sites.

[4] Million tons of coal equivalent

5 Implementation of insulation thickness optimization procedures in the demo sites

In this section, a technical definition regarding insulation thickness in each demo site is given. This definition takes into account the existing conditions such as wall structure or U-values. The concept of optimum thermal insulation thickness considers both the initial cost of the insulation and the energy savings over the life cycle of the insulation material. All the data related to Spanish, Turkish and Swedish demo sites were provided by different partners of CITyFiED consortium. For each demo site, the values are compared with the corresponding BEST.

5.1 Technical definition of the demo sites

A description of the three demo site current status, needed to acquire an intensive knowledge about their actual situation, is an essential first step for the design phase and also for future comparisons both with the CITyFiED strategy implementation result and other areas, as potential subjects of similar interventions.

5.1.1 Spanish demo site

Valladolid and its surrounding area, according to the Spanish National Climate Classification are included in Zone II, with Mediterranean-continental climatic conditions. Temperatures are very extreme, with big differences between day and night. Winters are cold, with frequent foggy days and frosts around 60 days per year. Summers are hot and dry but present low minimum temperatures during the night.

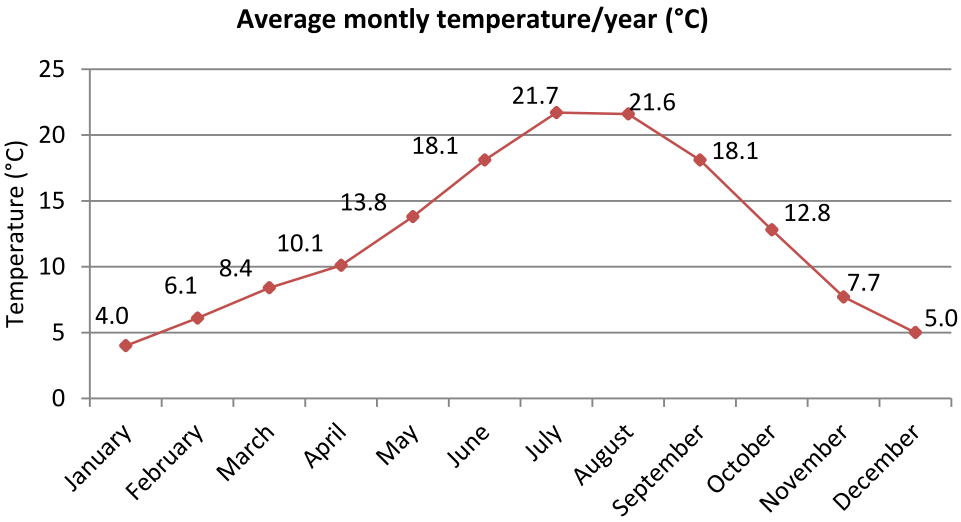


Figure 5.1: Monthly average temperatures in Valladolid (Spain).

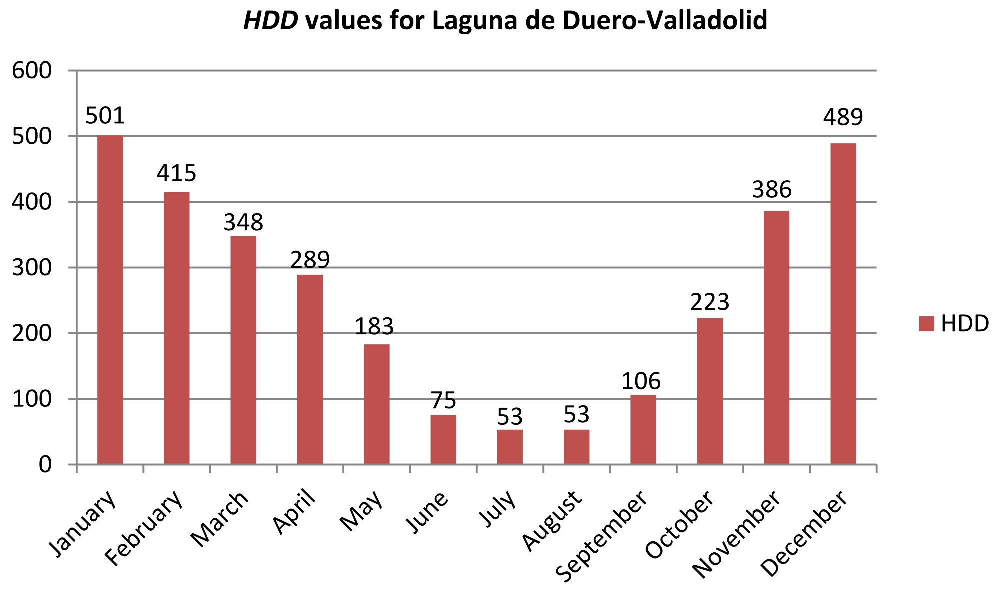


Figure 5.2: Heating degree days in Laguna de Duero-Valladolid/Spain (44).
(20°C is the base temperature for calculations in Laguna de Duero-Valladolid)

Torrelago is a homogeneous residential area located in Laguna de Duero and made of medium constructive quality buildings constructed around 1980 that are nowadays a progressive ageing. The district is formed by 31 buildings that respond to three different typologies, A, B and C, containing a total 1,488 dwellings.

All the blocks are H shaped, and their dimmensions presents little variations depending on the typology.

Figure 5.3: Block type B plans.
Source: CITyFiED deliverable D4.1

For calculations, B block type is selected because this type has more blocks. B building has ground plus twelve floor levels, occupied by an entrance hall and a total of 48 dwellings with a surface of about 80 m^2(composed of hall, living room, corridor, three bedrooms, two bathrooms, kitchen and balcony) or 95 m^2 (with four bedrooms instead of three). For B block, the façade wall area is 3,300m^2, considering 12 floors.

The façade is made of brick cavity walls without insulation layer (12 cm ceramic brick + 5 cm air chamber + 7 cm ceramic brick + 1.5 cm gypsum plaster) and presents numerous pathologies, such as thermal bridges, fissures due to thermal expansion, fissures along the expansion joints or air infiltration through the facade.

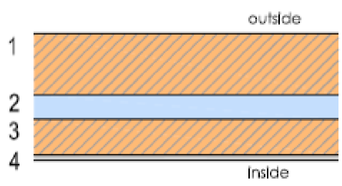
Element	Detail	Picture
1. Ceramic brick wall of 12 cm 2. Air chamber of 5 cm 3. Ceramic brick wall of 7 cm 4. Gypsum plaster of 1.5 cm		

Table 5.1: Brick cavity wall detail.
Source: CITyFiED deliverable D4.1

Zone	Useful area [m^2]	Built area [m^2]	Conditioned area [m^2] [i]
Type A block	4372.88	5,372.19	4,228.08
Type B block	4,727.50	5,534.64	4,579.92
Type C block	4,989.93	6,014.42	4,930.80
5 Type A blocks	21,864.40	26,860.95	21,140.40
18 Type B blocks	85,095.09	99,623.55	82,438.56
8 Type C blocks	39,919.46	48,115.37	39,446.40
Phase I CCPP	55,311.56	65,765.89	53,551.68
Phase II CCPP	91,567.39	108,833.98	89,473.68
TOTAL TORRELAGO	**146,878.94**	**174,599.87**	**143,025.36**

Table 5.2: Useful, built and conditioned area in Torrelago district by building typology and phase.
Source: CITyFiED deliverable D4.1

5.1.2 Turkish demo site

Soma is a town and district of Manisa Province in the Aegean region of Turkey. The demo area includes 82 buildings in total and 33 three story residential buildings, 32 two story buildings, 8 duplex and 6 one story residential buildings. Moreover, the demo site area includes lodging for single people, a kindergarten, a guess home and a convention centre. Below, details of each building type can be found. Soma weather data is as follows.

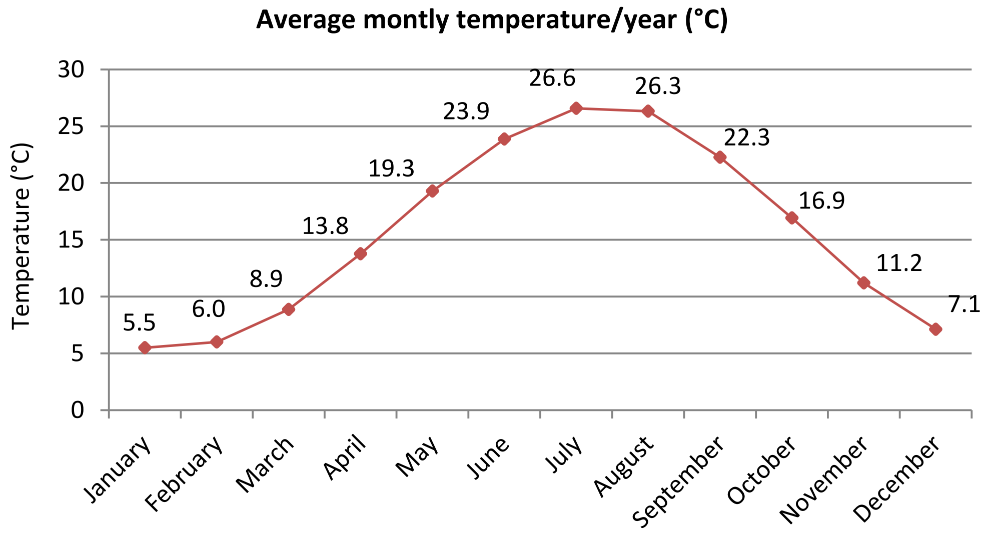


Figure 5.4: Monthly average temperatures in Soma (Turkey)

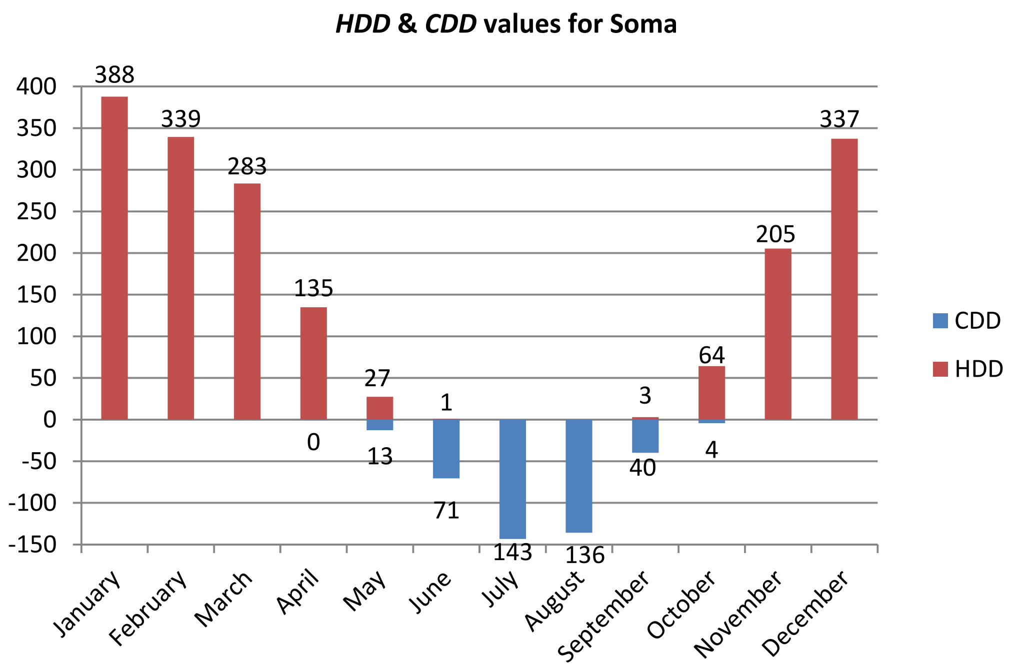


Figure 5.5: Heating and cooling degree days in Soma/Turkey
(20°C is the base temperature for calculations in Soma)

The calculations for the Turkish demo site are made by RETScreen Plus programme that is a windows-based energy management software tool that allows project owners to easily verify the data as weather, water consumption, electricity production etc. for the selected location.

Buildings of the demonstration district are owned by SOMA Electricity Generation & Trading Joint Stock Company and being used for its personnel. The "Soma Power Plant Lodging Buildings" site has nearly 217,600 m2 land area that include 31 year old 82 blocks with a total of 346 apartments, 2 guest houses and 1 convention centre.

- **Residential building blocks** have a total 59,297 m^2 gross area and 36,257m^2 conditioned area as they are,
  - 3 story; 33 building blocks, (32,535 m^2 gross area – 20,374 m^2 conditioned area)
  - 2 story; 32 building blocks, (22,506 m^2 gross area – 13,171 m^2 conditioned area)
  - 1 story; 6 building blocks, (2,524 m^2 gross area – 1,235 m^2 conditioned area)
  - Duplex; 8 building blocks, (1,733 m^2 gross area – 1,477 m^2 conditioned area)
- **Guest houses** have two building blocks and total 3,028 m^2 gross area and 2,470 m^2 conditioned area.
- **Convention centre** has a total 2,646 m^2 gross area and 2,431 m^2 conditioned area.

A three story building is selected to be studied.

3 story residential

Total gross area for each block: 986 m^2

Conditioned area for each block: 617 m^2

Number of blocks: 33

Summary of façade areas	Area [m^2]
Façade windows and doors excluded	632
Window double glazed – PVC frame	100
Door double glazed – PVC frame	51
Roof pitched roof	291

REVIT Model

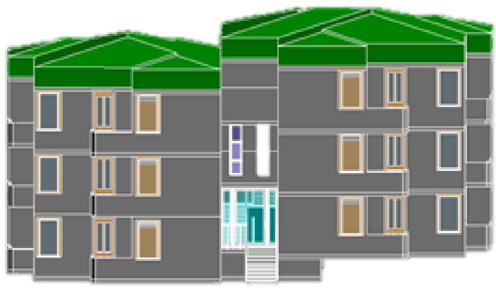


Table 5.3: Building models for 3 story residential block
Source: CITyFiED deliverable D4.2

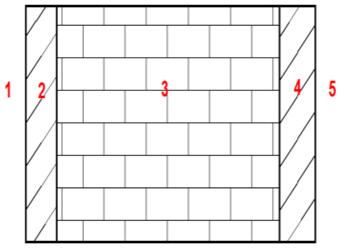
Element description	Detail (section's sketch from inner face to outer face)	Picture
External wall 1. Internal Paint 2. Internal Plaster (2 cm) 3. BrickWall (25 cm) 4. External Plaster (2 cm) 5. External Paint U-value = 1.786 W/(m^{2}K)		

Table 5.4: Detailed properties of external wall.
Source: CITyFiED deliverable D4.2

5.1.3 Swedish demo site

The district of Linero, created in 1969, is in the eastern part of Lund. Today it has a population of about 6,000 in detached houses, terraced houses and flats. Lund weather data is as follows:

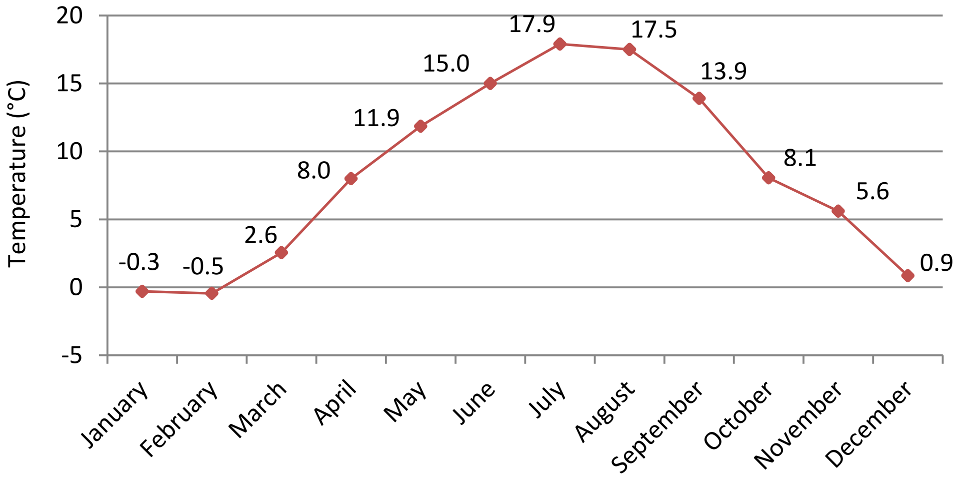


Figure 5.6: Monthly average temperatures in Lund (Sweden)

For Lund, Malmö weather data is used because reliable data. Considering that Lund and Malmö are close-range cities, these data is appropriate to use.

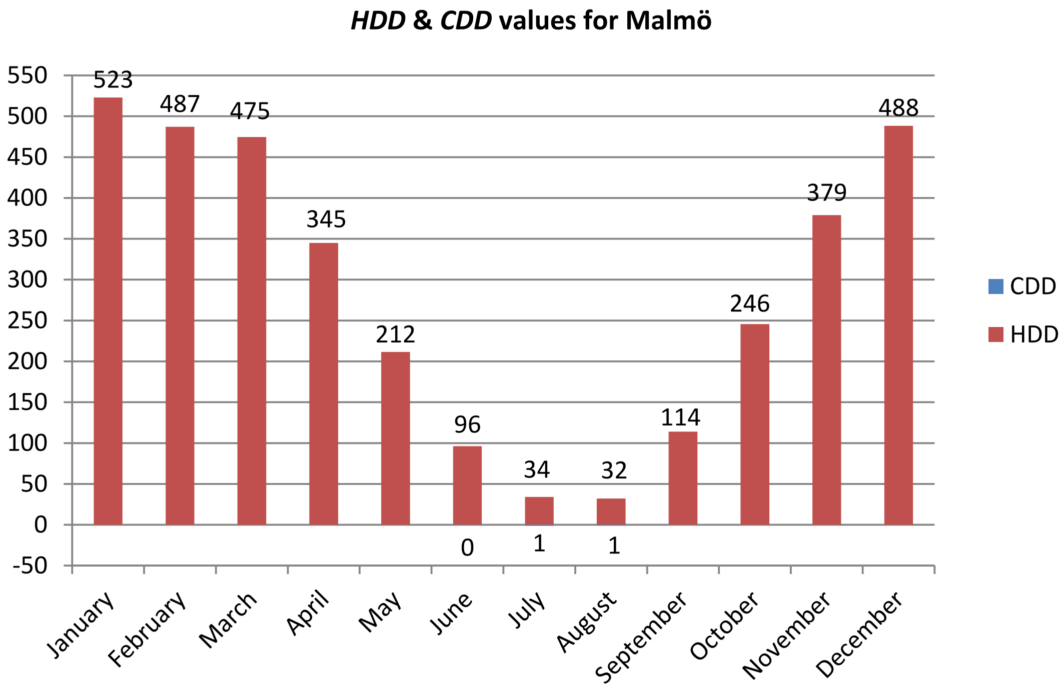


Figure 5.7: Heating and cooling degree days in Malmö/Sweden
(17°C is the base temperature for calculations in Malmö)

All buildings in the area are almost identical in appearance and design. In all buildings the entrances face north and the balconies south. Most of the buildings have three stairwells; however, a few have two or four stairwells.

Outside walls/façade walls

There are three different types of outside walls:

Structure of the end façade up to the attic floor		Structure of the end façade above the attic floor	
80	Concrete	80	Concrete
100	Polystyrene	80	Polystyrene
100	Concrete	100	Concrete

Structure of the entrance façade	
80	Concrete laid on concrete connections acting as brackets from the intermediate floor structure
Appr. 30	Air
–	Windproof board
95	Wooden studs 2" x 4" c/c 600 + mineral wool
–	Vapour barrier
13	Plaster

Table 5.5: Structure of the entrance façade

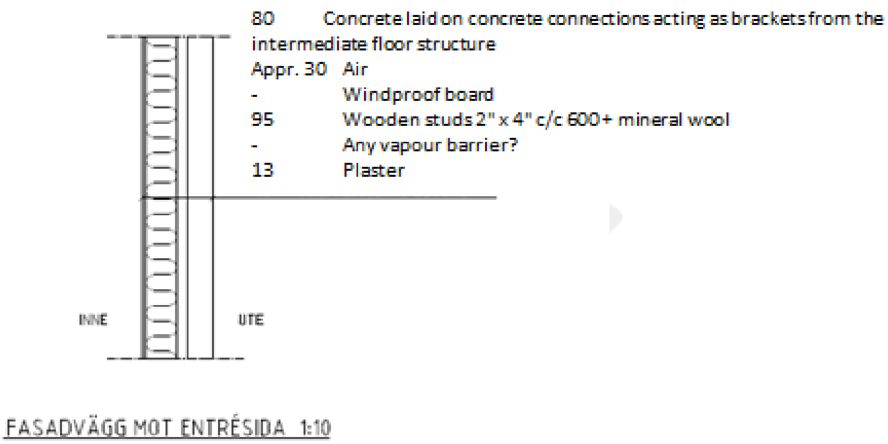


Figure 5.8: Structure of the entrance façade
Source: CITyFiED deliverable D4.3

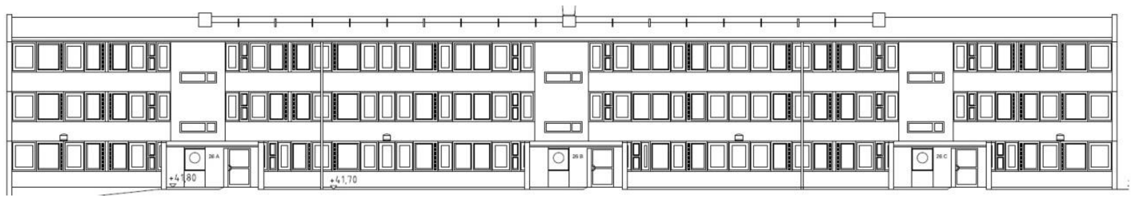


Figure 5.9: Drawing of the north façade with the stairwells
Source: CITyFiED deliverable D4.3

5.1.4 U-values for building elements

The building envelope and its thermal characteristics are identified by their envelope (external wall, roof, ground floor and windows) and the information is given in the table below and these properties are the same for all buildings.

U-value	Construction elements				Windows	
	External wall	Roof	Slab	Partition	Frame	Glass
Spanish demo site	1.36 W/m^{2}C	0.82W/m^{2}C	1.70 W/m^{2}C	1.64 W/m^{2}C	3.8 W/m^{2}C	3.7 W/m^{2}C
Turkish demo site	1.78 W/m^{2}C	0.73W/m^{2}C	2.839W/m^{2}C	0.45 W/m^{2}C	2.34 W/m^{2}C	
Swedish demo site	0.35 W/m^{2}C 0.5 W/m^{2}C	0.30W/m^{2}C	0.4 W/m^{2}C 0.79 W/m^{2}C	-	2.7 W/m^{2}C	2 W/m^{2}C

Table 5.6: Existing U-values for building elements for each demo-site.
Source: CITyFiED deliverables D4.1, D4.2 and D4.3

5.2 Implementation of insulation thickness optimization procedures in the Spanish demo site

A technical definition regarding insulation thickness in each demo site is given. The implementation of insulation thickness optimization procedure in the Spanish demo site (Laguna de Duero-Valladolid) gives the results shown below.

Parameter		Value
r	Interest rate adapted for inflation rate	2.8461
PWF	Present Worth Factor	0.3513
x_{opt} (m)	Optimum insulation thickness	0.042
x_{opt} (cm)	Optimum insulation thickness	4.25

Table 5.7: Optimum thickness calculation results for the Spanish demo site

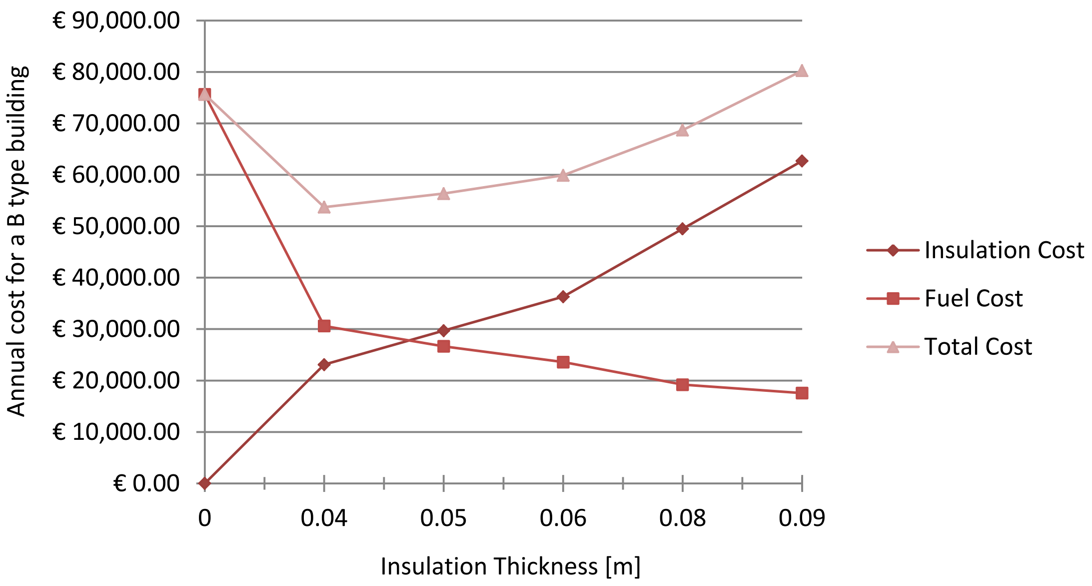


Figure 5.10: Annual costs versus insulation thickness for B block located in the Spanish demo site

Considering the results, for Laguna de Duero-Valladolid demo site, the insulation thickness would be around 4 cm of EPS, according to the parameters above. These results show that the existing conditions can be improved to avoid energy waste in the buildings.

Increasing the insulation thickness improves the energy savings to a certain extent. This point is the optimum value with some parameters such as inflation rate, degree day and fuel efficiency.

It is should be noticed that the optimal insulation thickness has been calculated in terms of economic savings considering the prices of fuel and implementation of the ETICS solution in the demo site. However, this insulation thickness fail to achieve the energy-saving targets raised in the CITyFiED Annex I – "Description of Work". In this regard and following the Spanish Technical Building Code[5], the thickness of the insulation layer (EPS) of the ETICS solution deployed in the Spanish demo site was calculated as 8 cm.

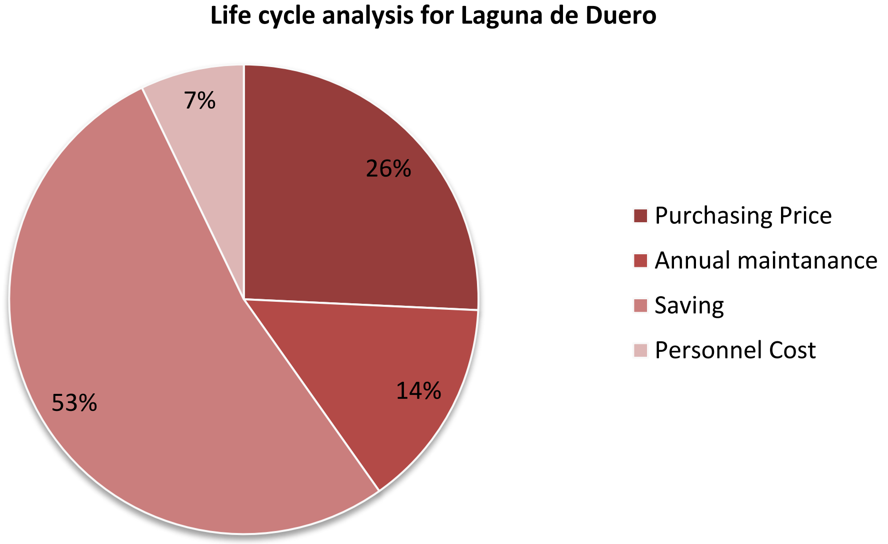


Figure 5.11: LCCA for Laguna de Duero demo site with 20 years system life

In Laguna de Duero, comparing to the existing condition, 2 Mtce/year will be saved. For 20 year, the saved energy equals 40 Mtce. Energetic and economic cost savings will be made for the Spanish demo site, which will have positive effects on reducing the energy demand and GHG emissions.

5.2.1 Comparison to the BEST

According to the BEST for the Spanish demo site, the U-value for the building walls was estimated as 1.22 W/m^{2}K. Nevertheless, following a more detailed study, which was carried out within Task 4.1 and described in the deliverable D4.1 "*Technical definition of the Spanish demo site"*, the U-value of the building walls was calculated as 1.36 W/m^{2}K.

Considering the ETICS solution, the U-value of the walls is reduced to 0.339 W/m^{2}K, which improves slightly the U-value suggested in the CITyFiED Annex I – "Description of Work" (0.392 W/m^{2}K).

The BEST for the Torrelago district in Laguna de Duero-Valladolid is:

[5] http://www.codigotecnico.org/ingles/introduction/

Building Energy Specification Table (BEST)				Community / site	LAGUNA VALLADOLID	SPAIN	BEST no. 1
1,1	**Building Category**		**Residential Retrofitted** [1]	total area / category / BEST sheet [2]		140000	m^2
1,2	**Local Climate**			January average outside temperature		°C	4,10
				August average outside temperature		°C	21,30
	Climatic Zone		D2	Average global horizontal radiation		kWh/m^2 yr	4,10
	(national definition)			Annual heating degree days [3]		°Cd/yr	1811,00
1,3	**Maximum requirements of building fabric**			Existing building	National regulation for new built	suggested specification	Energy savings [%]
	Façade/wall	U	W / m2K	1,22	0,66	0,392	-67,87%
	Roof	U	W / m2K	1,01		1,01	0,00%
	Ground floor	U	W / m2K	2,63		2,63	0,00%
	Glazing	U_g	W / m2K	5,7	2,6	2,6	-54,39%
	Average U-value	U_{av}	W / m2K	1,75		0,626	-64,23%
	Glazing	g	total solar energy transmittance of glazing [%]	0,85		0,76	-10,59%
	Shading	Fs	Shading correction factor				
	Ventilation rate [4]		air changes/hr	1		1	0,00%

Table 5.8: BEST for Laguna de Duero
Source: CITyFiED Annex I – "Description of Work"

5.3 Implementation of insulation thickness optimization procedures in the Turkish demo site

5.3.1 Conventional system

The implementation of insulation thickness optimization procedure in the Turkish demo site (Soma district in Manisa province) gives the results shown below.

Parameter		Value
r	Interest rate adapted for inflation rate	0.0291
PWF	Present Worth Factor	14.9937
x_{opt} (m)	Optimum insulation thickness	0.0679
x_{opt} (cm)	Optimum insulation thickness	6.79

Table 5.9: Optimum thickness calculation results for the Turkish demo site

For Soma, it should be approximately 7 cm to be able to reach an economic optimization. The payback period is about 2 years when considering the total annual energy requirements. After district heating implementation, buildings located in demo site will use surplus heat. Thereby, it can be assumed that all energy consumed will be saved with new investments for Soma demo site.

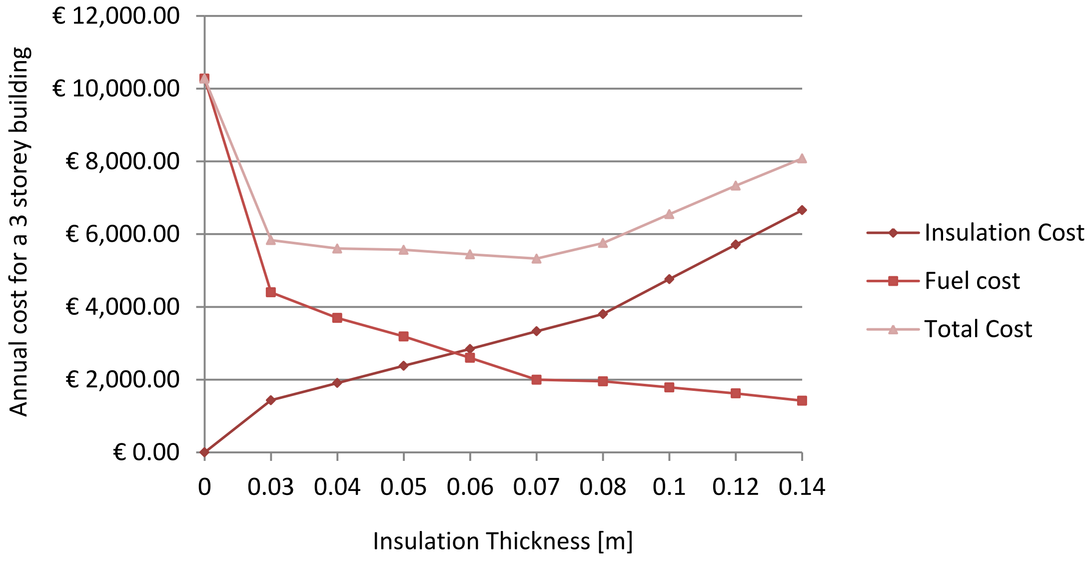


Figure 5.12: Heating and annual costs vs insulation thickness for 3 storey building for Soma demo site

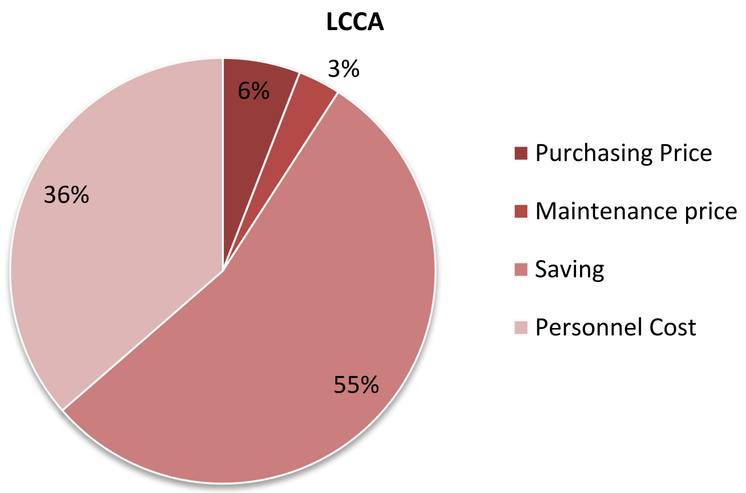


Figure 5.13: LCCA for Soma demo site with 20 years system life

In Soma, comparison with the existing condition, 121310 kWh-lignite/year will be saved.

$$1\ kg\ Soma\ lignite = 6.38\ kWh\ energy \quad \text{Equation 5.1}$$

$$1\ Mt\ lignite = 0.35\ Mtce \quad \text{Equation 5.2}$$

For 20 year, saved energy equals 133.09 Mtce for Soma demo site. One of the project aims is that view and focusing on environmental aspects, the retrofitting uptake of low efficient building has impact in terms of CO_2 emissions reduction, and improvement of the indoor air quality. Under these circumstances, both substantially energy saved and CO_2 emissions are reduced for Soma demo site.

5.3.2 Low temperature heating system

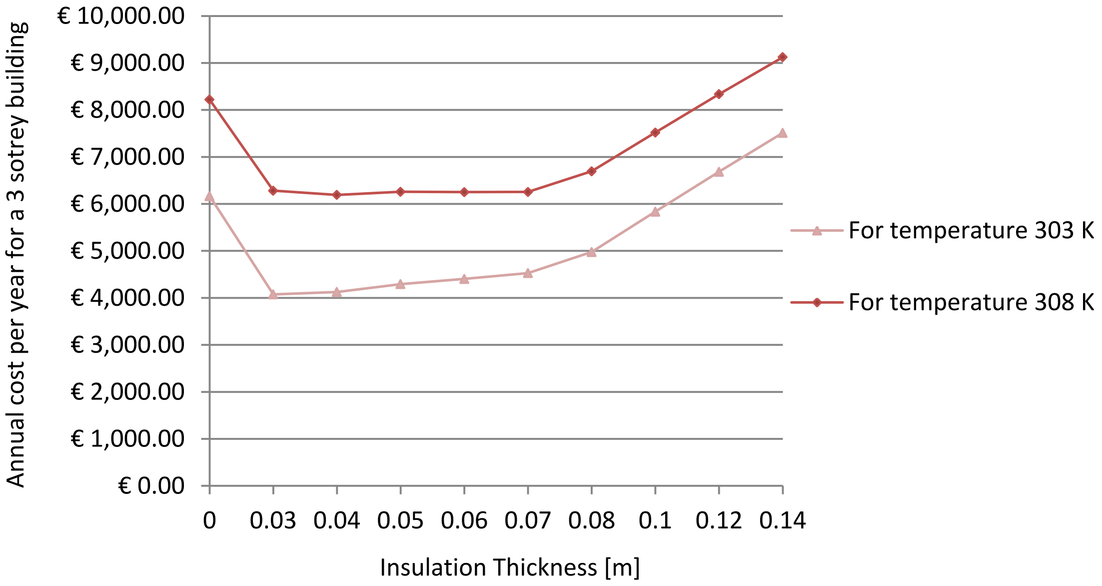


Figure 5.14: Annual costs versus insulation thickness with low temperature system for Soma

For inlet temperature of 303 K, optimum insulation thickness is 8.5 cm. Considering that radiant panels have 2 cm thickness, 6.5 cm thickness is appropriate for external walls. For inlet temperature 308 K, optimum insulation thickness is 9.5 cm. Considering that radiant panels have 2 cm thickness, 7.5 cm thickness is appropriate for external walls.

Thus, 6.5 cm data is more appropriate for our design, and also it has to be noted that in the next graphic, low temperature radiant panel price is added to façade wall price. This graphic shows that first year that low temperature heating system is implemented.

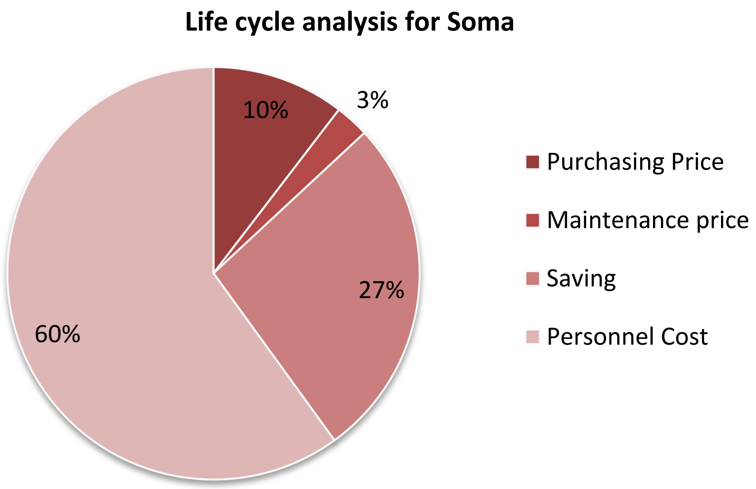


Figure 5.15: LCCA for Soma with 20 years system life for low temperature heating system

For LCCA analysis, according to conventional system graphic, more person month is considered because more time are needed for implementations. Additionally, radiant heating panel prices are added to purchasing price.

5.3.3 Comparison to the BEST

By reducing the U-value of the façade, heat losses are reduced about 14% for Soma. Implementation of radiant heating panels enables the heat losses to decrease. Thus, system efficiency is increased by means of using surplus heat from big thermal plant. All energy consumption prior to district heating implementation is provided by surplus heat from big thermal plant.

The new U-value for the building wall is 0.5 W/m^{2}K, as suggested in Annex I – "Document of Work" of CITyFiED.

The BEST for the Soma district in Manisa province is:

Building Energy Specification Table (BEST)				Community / site	SOMA	TURKEY	BEST no.
							1
1,1	Building Category		Residential Retrofitted [1]	total area / category / BEST sheet [2]		80980 m^2	
1,2	Local Climate			January average outside temperature		°C	5,5
				August average outside temperature		°C	23,5
	Climatic Zone		Moderate	Average global horizontal radiation		kWh/m^2 yr	1311
	(national definition)		Zone2	Annual heating degree days [3]		°Cd/yr	1433
1,3	Maximum requirements of building fabric			Existing building	National regulation for new built	suggested specification	Energy savings [%]
	Façade/wall	U	W / m2K	1,786	0,6	0,5	-72,00%
	Roof	U	W / m2K	0,732	0,4	0,2	-72,68%
	Ground floor	U	W / m2K	2,839	0,6	0,5	-82,39%
	Glazing	U_g	W / m2K	2,34	2,4	1,4	-40,17%
	Average U-value	U_{av}	W / m2K	1,708	1	1	-41,45%
	Glazing	g	total solar energy transmittance of glazing [%]				
	Shading	Fs	Shading correction factor	0,649			
	Ventilation rate [4]		air changes/hr				

Table 5.10: BEST for Soma demo-site.
Source: CITyFiED Annex I – "Description of Work"

5.4 Implementation of insulation thickness optimization procedures in the Swedish demo site

The implementation of insulation thickness optimization procedure in the Swedish demo site (Linero district) gives the results shown below.

Parameter		Value
r	Interest rate adapted for inflation rate	0.6154
PWF	Present Worth Factor	1.6249
x_{opt} (m)	Optimum insulation thickness	0.06
x_{opt} (cm)	Optimum insulation thickness	6.02

Table 5.11: Optimum thickness calculation results for the Swedish demo site

For Lund, the used fuel is already very efficient and its lower heating value is really high. In addition, the U-value for façade is very low. In Lund demo site, one of the external wall type already has 10 cm of EPS.

In Linero district, comparing with the existing condition, 17,605 kWh-gas/year will be saved. For 20 year, it equals to 23.59 Mtoe for Lund. One of the project aims is related to environmental aspects, the retrofitting of low efficient building has an impact in terms of CO_2 emissions reduction, and improvement of comfort conditions. In this sense, both building energy use and CO_2 emissions are reduced for Lund demo site.

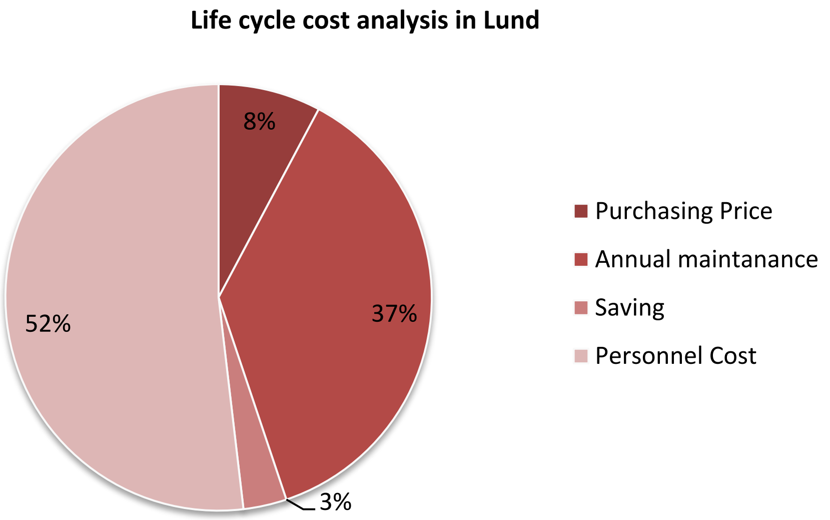


Figure 5.16: LCCA for Lund demo site with 20 years system life

5.4.1 Comparison to the BEST

According to the BEST for the Swedish demo site, the U-value for the building walls was estimated as 0.4 W/m^{2}K. In terms of building insulation, it should be noticed that the current situation of the Swedish demo site is considerably better than the situation of the other demo sites of the CITyFiED project.

Considering the results of the insulation thickness optimization procedure, the increase of the insulation thickness of the façade could be considered as a non-priority measure in terms of economic optimization. However, the retrofitting of the façade will be addressed and the average U-value will be improved from 0.8 W/m^{2}K to an average U-value of 0.5 W/m^{2}K in order to increase the energy efficient of the district and achieve the energy-saving targets raised in the CITyFiED Annex I – "Description of Work".

The BEST for Linero district in Lund is:

Building Energy Specification Table (BEST)					Community / site	Lund Linero	SWEDEN		BEST no.
									1
1,1	**Building Category**			**Residential Retrofitted**	total area / category / BEST sheet [2]		40400	m²	A-Temp
			[1]						
1,2	**Local Climate**				January average outside temperature		°C		1
					August average outside temperature		°C		18
	Climatic Zone			oceanic climate	Average global horizontal radiation		kWh/m² yr		963,4
	(national definition)			"climatic zone III"	Annual heating degree days [3]		°Cd/yr		3007
1,3	**Maximum requirements of building fabric**				Existing building	National regulation for new built	suggested specification		Energy savings [%]
	Façade/wall		U	W / m2K	0,4		0,3		-25,0%
	Roof		U	W / m2K	0,4		0,25		-37,5%
	Ground floor		U	W / m2K	0,4		0,3		-25,0%
	Glazing		U_g	W / m2K	2,0		1		-50,0%
	Average U-value		U_{av}	W / m2K	0,8	0,4	0,5		-42,2%
	Glazing		g	total solar energy transmittance of glazing [%]					
	Shading		Fs	Shading correction factor					
	Ventilation rate	[4]		air changes/hr	0,5				

Table 5.12: BEST for Linero district.
Source: CITyFiED Annex I – "Description of Work"

6 Conclusions

In deliverable D2.3 "*Report on methods for determining the optimum insulation thickness"*, optimal insulation materials and thickness for the buildings are determined. Thanks to this calculations, energetic and economic cost optimization can be made, which has positive effects on reducing the energy demand and GHG emissions.

The work presented in this deliverable allows to develop the technical objectives of the Subtask 2.1.3 *"Methods for determining insulation thickness"*

- To get a better knowledge of insulation materials,
- To globally understand the importance of insulation,
- To investigate optimum insulation thickness for each demo-sites,
- To reduce energy intensity and energy losses in industry and services sectors
- To decrease the energy demand and carbon emissions of the buildings by promoting sustainable environment friendly buildings and by using renewable energy sources
- To provide market transformation of energy efficient products
- To increase efficiency in production, transmission and distribution of electricity. And to decrease energy losses and harmful environment emissions
- To use energy effectively and efficiently in the public sector

The expected result of these strategies is that Laguna de Duero-Valladolid, Soma and Lund will lead other cities in Europe to constitute smart cities and districts, in order to improve the quality of life of people and to develop a cleaner world to live.

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