

Open University of Cyprus

Faculty of Pure and Applied Sciences

**Master of Science in
Sustainable Energy Systems**

MSc Thesis



**The Impact of the Implementation of the
European Energy Performance of Buildings Directive
on the European Building Stock:
The Case of the Cyprus Land Development Corporation**

Kyriacos Polycarpou

**Supervisor
Dr.-Ing Paris A. Fokaides**

June 2018

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A thesis submitted to the School of Engineering
of Open University of Cyprus & Frederick University Cyprus
in partial fulfillment of the requirements
for the degree of MASTER OF SCIENCE
in Sustainable Energy Systems

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School of Engineering

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Abstract

The necessity of reducing the global energy consumption led the European Union to the introduction of several relative policies and directives, with the objective of a gradual improvement of the energy performance of buildings and the reduction of energy consumption.

Since the adoption of the Energy Performance of Buildings Directive (EPBD) several developments had been implemented towards the European Union member States, applying significant energy saving measures on new and existing buildings but with lower intensity and magnitude in south Europe

Furthermore, the implementation of the EPBD and its effectiveness is still under discussion in some cases, one such being the buildings occupied by social housing recipients.

This study aims to simulate variable energy efficiency improvements and evaluate their performance on the building stock of a European member state, Cyprus, and particularly on the dwellings constructed by the national social-housing corporation, by reclaiming the findings of a previous case study concerning the analysis of the impact of the EPBD implementation on the building stock of the under-review corporation.

Table of Contents

CHAPTER 1 INTRODUCTION	1
1.1. SCOPE OF THE STUDY	1
1.2. OBJECTIVE OF THE STUDY	2
CHAPTER 2 THEORETICAL BACKGROUND	4
2.1. ENERGY EFFICIENCY ON THE RESIDENTIAL SECTOR.....	4
2.2. SOCIAL HOUSING SECTOR IN THE EUROPEAN UNION	5
2.3. SOCIAL HOUSING IN CYPRUS.....	6
2.4. ENERGY EFFICIENCY OF SOCIAL HOUSING DWELLINGS.....	6
2.5. BUILDING INFORMATION MODELLING	7
CHAPTER 3 METHODOLOGY.....	8
CHAPTER 4 ANALYSIS OF MODELS.....	9
4.1. PREPARATION OF MODELS	9
4.1.1 <i>Elements Used for the Simulation</i>	10
Walls	10
Floors.....	12
Roofs.....	13
4.1.2 <i>Model of Category P₁</i>	14

P1: Plan Views.....	17
P1: 3D Views.....	17
P ₁ – Elevations.....	17
P ₁ : Sections.....	18
<i>4.1.3 Model of Category P₂</i>	<i>19</i>
P ₂ : Plan Views.....	22
P ₂ : 3D Views.....	22
P ₂ – Elevations.....	22
P ₂ - Sections.....	23
<i>4.1.4 Model of Category P₃</i>	<i>24</i>
P ₃ : Plan Views.....	26
P ₃ : 3D Views.....	27
P ₃ – Elevations.....	27
P ₃ - Sections.....	28
4.2. EXISTING THERMAL CHARACTERISTICS.....	30
<i>4.2.1 Existing Characteristics of Model P₁</i>	<i>30</i>
<i>4.2.2 Existing Characteristics of Model P₂</i>	<i>30</i>
<i>4.2.3 Existing Characteristics of Model P₃</i>	<i>31</i>
4.3. WEATHER DATA.....	51
<i>4.3.1 Category P₁</i>	<i>51</i>
<i>4.3.2 Category P₂</i>	<i>55</i>

4.3.3	<i>Category P3</i>	60
4.4.	ENERGY MODELS	61
4.4.1	<i>Category P1: Energy Model, Spaces and Surfaces</i>	61
4.4.2	<i>Category P2: Energy Model, Spaces and Surfaces</i>	63
4.4.3	<i>Category P3: Energy Model, Spaces and Surfaces</i>	64
4.4.4	64
4.5.	ENERGY SETTINGS	66
4.6.	ASSESSMENT OF ENERGY USE INTENSITY	69
4.6.1	<i>Model P₁</i>	69
4.6.2	<i>Model P₂</i>	69
4.6.3	<i>Model P₃</i>	70
4.7.	DESIGN ALTERNATIVES.....	71
4.7.1	<i>Model P₁: Energy Use Intensity</i>	72
4.7.2	<i>Model P₂: Energy Use Intensity</i>	72
4.7.3	<i>Model P₃: Energy Use Intensity</i>	72
4.8.	ADJUSTMENT OF ENERGY SETTINGS.....	75
4.9.	FINAL ENERGY USE INTENSITY	82
4.9.1	<i>Model P₁: Energy Use Intensity / Adjustments</i>	82
4.9.2	<i>Model P₂: Energy Use Intensity / Adjustments</i>	87
4.9.3	<i>Model P₃: Energy Use Intensity</i>	92
	Trial 1	95

Trial 2	95
CHAPTER 5 ECONOMIC ANALYSIS.....	99
5.1. COST OF INTERVENTIONS.....	99
5.2. COST ESTIMATION	100
5.2.1 <i>Model P1: Calculation of Investment for Interventions</i>	101
5.2.2 <i>Model P2: Calculation of Investment for Interventions</i>	102
5.2.3 <i>Model P3: Calculation of Investment for Interventions</i>	104
5.3. CALCULATION OF ANNUAL ENERGY SAVINGS.....	105
5.3.1 <i>Model P1: Annual Energy Savings</i>	105
5.3.2 <i>Model P2: Annual Energy Savings</i>	106
5.3.3 <i>Model P3: Annual Energy Savings</i>	106
5.4. PAYBACK PERIOD.....	108
5.4.1 <i>Model P1</i>	108
P1-Option 2	108
P1- Option 3	110
5.4.2 <i>Model P2</i>	112
P2- Option 2	112
P2- Option 3	114
5.4.3 <i>Model P3</i>	117
P3- Option 2	117
P3- Option 3	119

5.4.4	<i>Trial Case: Add Renewables – Ignore Present Value</i>	121
CHAPTER 6 RESULTS AND DISCUSSION		123
6.1.	OBJECTIVE AND OUTCOMES OF THE STUDY	123
6.2.	OVERALL REDUCTION OF ENERGY USE INTENSITY.....	124
6.3.	GLAZING TYPE	125
CHAPTER 7 RECOMMENDATIONS – FURTHER RESEARCH		126
BIBLIOGRAPHY		1

Index of Tables

TABLE 1: CATEGORY P ₁ – FLOORS / LEVELS.....	15
TABLE 2: CATEGORY P ₁ - ROOMS.....	15
TABLE 3: CATEGORY P ₂ – FLOORS / LEVELS.....	20
TABLE 4: CATEGORY P ₂ - ROOMS.....	20
TABLE 5: CATEGORY P ₃ – FLOORS / LEVELS.....	25
TABLE 6: CATEGORY P ₂ - ROOMS.....	25
TABLE 7: CATEGORY P ₁ – SIMULATION ASSUMPTIONS/ LOCATION.....	32
TABLE 8: CATEGORY P ₁ – SIMULATION ASSUMPTIONS/ ELEMENTS.....	33
TABLE 9: CATEGORY P ₂ – SIMULATION ASSUMPTIONS/ LOCATION.....	39
TABLE 10: CATEGORY P ₂ – SIMULATION ASSUMPTIONS/ ELEMENTS	40
TABLE 11: CATEGORY P ₃ – SIMULATION ASSUMPTIONS/ LOCATION	44
TABLE 12: CATEGORY P ₃ – SIMULATION ASSUMPTIONS/ ELEMENTS	46
TABLE 13: P ₁ : WEATHER SUMMARY.....	52
TABLE 14: P ₂ : WEATHER SUMMARY.....	56
TABLE 15: P ₃ : WEATHER SUMMARY	61
TABLE 16: CATEGORY P ₁ – ANALYTICAL SPACES.....	62
TABLE 17: CATEGORY P ₁ – ANALYTICAL SURFACES	62
TABLE 18: CATEGORY P ₂ – ANALYTICAL SPACES.....	63

TABLE 19: CATEGORY P ₂ – ANALYTICAL SURFACES	64
TABLE 20: CATEGORY P ₃ – ANALYTICAL SPACES	65
TABLE 21: CATEGORY P ₃ – ANALYTICAL SURFACES	65
TABLE 22: ENERGY SETTINGS APPLIED IN ALL MODELS.....	66
TABLE 23: RESULTED ANNUAL COST AND ANNUAL ENERGY USE INTENSITY OF EACH DESIGN OPTION	73
TABLE 24: PARAMETERS CONSIDERED FOR THE ADJUSTMENTS ON ENERGY SETTINGS	75
TABLE 25: ADJUSTMENTS ON ENERGY SETTINGS	80
TABLE 26: P ₁ -INSIGHT 360 OPTIMUM DESIGN ALTERNATIVES	85
TABLE 27: P ₂ -INSIGHT 360 OPTIMUM DESIGN ALTERNATIVES	89
TABLE 28: P ₃ -INSIGHT 360 OPTIMUM DESIGN ALTERNATIVES	93
TABLE 29: SUMMARY OF ENERGY USE INTENSITY OF ALTERNATIVE DESIGN OPTIONS OF MODELS.....	98
TABLE 30: PRICING ASSUMPTIONS FOR THE CALCULATION OF PROPOSED MEASURES.....	100
TABLE 31: MODEL P ₁ - ESTIMATION OF ELEMENT QUANTITIES	101
TABLE 32: MODEL P ₃ - INVESTMENT COST BREAKDOWN OF PROPOSED MEASURES.....	101
TABLE 33: MODEL P ₂ - ESTIMATION OF ELEMENT QUANTITIES	102
TABLE 34: MODEL P ₂ - INVESTMENT COST BREAKDOWN OF PROPOSED MEASURES.....	103
TABLE 35: MODEL P ₃ - ESTIMATION OF ELEMENT QUANTITIES	104
TABLE 36: MODEL P ₂ - INVESTMENT COST BREAKDOWN OF PROPOSED MEASURES.....	104
TABLE 37: ALL MODELS- CALCULATION OF ANNUAL SAVINGS	107
TABLE 38: P ₁ -OPTION 2- CALCULATION OF PAYBACK PERIOD	108
TABLE 39: P ₁ -OPTION 3- CALCULATION OF PAYBACK PERIOD	110

TABLE 40: P ₂ -OPTION 2- CALCULATION OF PAYBACK PERIOD	112
TABLE 41: P ₂ -OPTION 3- CALCULATION OF PAYBACK PERIOD	114
TABLE 42: P ₃ -OPTION 2 CALCULATION OF PAYBACK PERIOD	117
TABLE 43: P ₃ -OPTION 3 CALCULATION OF PAYBACK PERIOD.....	119

Index of Figures

FIGURE 1: INTERIOR BRICK WALL 100MM.....	10
FIGURE 2: INTERIOR BRICK WALL 200MM.....	10
FIGURE 3: EXTERIOR BRICK WALL 200MM.....	10
FIGURE 4: INTERIOR SHEAR WALL 200MM.....	10
FIGURE 5: INTERIOR BRICK WALL 250MM.....	10
FIGURE 6: INTERIOR BRICK WALL 250MM +5CM EXTERNAL INSULATION.....	11
FIGURE 7: INTERIOR BRICK WALL 250MM +10CM EXTERNAL INSULATION.....	11
FIGURE 8: EXTERIOR BRICK WALL 250MM.....	11
FIGURE 9: EXTERIOR BRICK WALL 250MM +5CM EXTERNAL INSULATION.....	11
FIGURE 10: EXTERIOR BRICK WALL 250MM +10CM EXTERNAL INSULATION.....	11
FIGURE 11: EXTERIOR BRICK WALL 250MM WITH GAP + 5CM EXTERNAL INSULATION.....	11
FIGURE 12: INTERIOR BRICK WALL 250MM WITH GAP + 5CM EXTERNAL INSULATION.....	12
FIGURE 13: EXTERIOR BRICK WALL 250MM WITH GAP + 10CM EXTERNAL INSULATION.....	12
FIGURE 14: INTERIOR BRICK WALL 250MM WITH GAP + 10CM EXTERNAL INSULATION.....	12
FIGURE 15: INTERIOR BRICK WALL 250MM WITH GAP.....	12
FIGURE 16: EXTERIOR BRICK WALL 250MM WITH GAP.....	12
FIGURE 17: EXPOSED FLOOR (P1-P2).....	12
FIGURE 18: INTERIOR FLOOR (P1-P2).....	13

FIGURE 19: EXPOSED FLOOR (P3)	13
FIGURE 20: INTERIOR FLOOR (P3)	13
FIGURE 21: ROOF (P1-P2).....	13
FIGURE 22: ROOF (P1-P2) + 5CM EXTERNAL INSULATION	13
FIGURE 23: ROOF (P1-P2) + 10CM EXTERNAL INSULATION.....	13
FIGURE 24: ROOF (P3).....	14
FIGURE 25: ROOF (P3) + 5CM EXTERNAL INSULATION	14
FIGURE 26: ROOF (P3) + 10CM EXTERNAL INSULATION.....	14
FIGURE 27: P1 -GROUND FLOOR.....	17
FIGURE 28: P1 -FIRST FLOOR.....	17
FIGURE 29: P1 - ROOF PLAN	17
FIGURE 30: P1 - 3D VIEWS.....	17
FIGURE 31: P1 - 3D VIEWS.....	17
FIGURE 32: P1 - 3D VIEWS.....	17
FIGURE 33: P1 - EAST ELEVATION.....	17
FIGURE 34: P1 - NORTH ELEVATION	17
FIGURE 35: P1 - SOUTH ELEVATION	18
FIGURE 36: P1 - WEST ELEVATION	18
FIGURE 37: SECTIONS (LAYOUT)	18
FIGURE 38: P1 - SECTION A	18
FIGURE 39: P1 - SECTION B	18

FIGURE 40: P ₁ - SECTION C	18
FIGURE 41: P ₁ - SECTION D.....	18
FIGURE 42: P ₁ - SECTION E	18
FIGURE 43: P ₁ - SECTION F	18
FIGURE 44: P ₁ – SECTION G	19
FIGURE 45: P ₁ – SECTION H.....	19
FIGURE 46: P ₁ – SECTION I.....	19
FIGURE 47: P ₂ -GROUND FLOOR.....	22
FIGURE 48: P ₂ - FIRST FLOOR.....	22
FIGURE 49: P ₂ - ROOF.....	22
FIGURE 50: P ₂ – 3D VIEWS.....	22
FIGURE 51: P ₂ – 3D VIEWS.....	22
FIGURE 52: P ₂ – 3D VIEWS.....	22
FIGURE 53: P ₂ – EAST ELEVATION.....	22
FIGURE 54: P ₂ – NORTH ELEVATION	22
FIGURE 55: P ₂ – SOUTH ELEVATION.....	23
FIGURE 56: P ₂ – WEST ELEVATION.....	23
FIGURE 57: SECTIONS LAYOUT.....	23
FIGURE 58: P ₂ – SECTION A-A.....	23
FIGURE 59: P ₂ – SECTION B-B.....	23
FIGURE 60: P ₂ – SECTION C-C.....	23

FIGURE 61: P ₂ – SECTION D-D	23
FIGURE 62: P ₂ – SECTION E-E	23
<i>FIGURE 63: P₂ – SECTION F-F</i>	24
FIGURE 64: P ₂ – SECTION G-G.....	24
FIGURE 65: P ₂ – SECTION H-H.....	24
FIGURE 66: P ₃ -GROUND FLOOR.....	26
FIGURE 67: P ₃ -GROUND FLOOR.....	26
FIGURE 68: P ₃ -GROUND FLOOR.....	26
FIGURE 69: P ₂ – 3D VIEWS	27
FIGURE 70: P ₂ – 3D VIEWS	27
FIGURE 71: P ₂ – 3D VIEWS	27
FIGURE 72: P ₃ – EAST ELEVATION	27
FIGURE 73: P ₃ – NORTH ELEVATION	27
FIGURE 74: P ₂ – SOUTH ELEVATION	27
FIGURE 75: P ₂ – WEST ELEVATION.....	27
FIGURE 76: SECTIONS (LAYOUT)	28
FIGURE 77: P ₃ – SECTION A-A.....	28
FIGURE 78: P ₃ – SECTION B-B.....	28
FIGURE 79: P ₃ – SECTION C-C	28
FIGURE 80: P ₃ – SECTION D-D	28
FIGURE 81: P ₃ – SECTION E-E.....	28

FIGURE 82: P ₃ – SECTION F-F	28
FIGURE 83: P ₃ – SECTION G-G.....	29
FIGURE 84: P ₃ – SECTION H-H.....	29
FIGURE 85: P ₃ – SECTION I-I	29
FIGURE 86: P ₁ – LOCATION – CLOSEST METEOROLOGICAL STATION	51
FIGURE 87: P ₁ – TEMPERATURE DISTRIBUTION (INSIGHT 360)	51
FIGURE 88: P ₁ – WINDROSE SPEED (INSIGHT 360).....	51
FIGURE 89: P ₁ –GREEN BUILDING STUDIO WEATHER STATION	52
FIGURE 90: P ₁ –DRY BULB FREQUENCY DISTRIBUTION.....	52
FIGURE 91: P ₁ –DRY BULB CUMULATIVE DISTRIBUTION.....	52
FIGURE 92: P ₁ –DEW POINT FREQUENCY DISTRIBUTION	53
FIGURE 93: P ₁ –DEW POINT CUMULATIVE DISTRIBUTION	53
FIGURE 94: P ₁ –RELATIVE HUMIDITY FREQUENCY DISTRIBUTION.....	53
FIGURE 95: P ₁ –RELATIVE HUMIDITY CUMULATIVE DISTRIBUTION.....	53
FIGURE 96: P ₁ –WIND SPEED FREQUENCY DISTRIBUTION	53
FIGURE 97: P ₁ –WIND SPEED CUMULATIVE DISTRIBUTION	53
FIGURE 98: P ₁ –TOTAL SKY COVER FREQUENCY DISTRIBUTION.....	54
FIGURE 99: P ₁ –TOTAL SKY COVER CUMULATIVE DISTRIBUTION.....	54
FIGURE 100: P ₁ –DIRECT NORMAL RADIATION FREQUENCY DISTRIBUTION	54
FIGURE 101: P ₁ –DIRECT NORMAL RADIATION CUMULATIVE DISTRIBUTION	54
FIGURE 102: P ₁ –DIFFUSE HORIZONTAL RADIATION FREQUENCY DISTRIBUTION.....	54

FIGURE 103: P1–DIFFUSE HORIZONTAL RADIATION CUMULATIVE DISTRIBUTION	54
FIGURE 104: P1–GLOBAL HORIZONTAL RADIATION FREQUENCY DISTRIBUTION.....	55
FIGURE 105: P1–GLOBAL HORIZONTAL RADIATION CUMULATIVE DISTRIBUTION.....	55
FIGURE 106: P1–WIND ROSE	55
FIGURE 107: P1–MONTHLY DESIGN DATA	55
FIGURE 108: P ₂ – LOCATION – CLOSEST METEOROLOGICAL STATION.....	55
FIGURE 109: P ₂ – TEMPERATURE DISTRIBUTION (INSIGHT 360).....	56
FIGURE 110: P ₁ – WINDROSE SPEED (INSIGHT 360)	56
FIGURE 111: P ₂ –GREEN BUILDING STUDIO WEATHER STATION.....	56
FIGURE 112: P ₂ –DRY BULB FREQUENCY DISTRIBUTION	57
FIGURE 113: P ₂ –DRY BULB CUMULATIVE DISTRIBUTION	57
FIGURE 114: P ₂ –DEW POINT FREQUENCY DISTRIBUTION	57
FIGURE 115: P ₂ –DEW POINT CUMULATIVE DISTRIBUTION	57
FIGURE 116: P ₂ –RELATIVE HUMIDITY FREQUENCY DISTRIBUTION.....	57
FIGURE 117: P ₂ –RELATIVE HUMIDITY CUMULATIVE DISTRIBUTION.....	57
FIGURE 118: P ₂ –WIND SPEED FREQUENCY DISTRIBUTION	58
FIGURE 119: P ₂ –WIND SPEED CUMULATIVE DISTRIBUTION	58
FIGURE 120: P ₂ –TOTAL SKY COVER FREQUENCY DISTRIBUTION.....	58
FIGURE 121: P ₂ –TOTAL SKY COVER CUMULATIVE DISTRIBUTION.....	58
FIGURE 122: P ₂ –DIRECT NORMAL RADIATION FREQUENCY DISTRIBUTION.....	58
FIGURE 123: P ₂ –DIRECT NORMAL RADIATION CUMULATIVE DISTRIBUTION	58

FIGURE 124: P ₂ –DIFFUSE HORIZONTAL RADIATION FREQUENCY DISTRIBUTION.....	59
FIGURE 125: P ₂ –DIFFUSE HORIZONTAL RADIATION CUMULATIVE DISTRIBUTION.....	59
FIGURE 126: P ₂ –GLOBAL HORIZONTAL RADIATION FREQUENCY DISTRIBUTION.....	59
FIGURE 127: P ₂ –GLOBAL HORIZONTAL RADIATION CUMULATIVE DISTRIBUTION.....	59
FIGURE 128: P ₂ –WIND ROSE	59
FIGURE 129: P ₂ –MONTHLY DESIGN DATA	59
FIGURE 130: P ₃ –GREEN BUILDING STUDIO WEATHER STATION.....	60
FIGURE 131: P ₃ – LOCATION – CLOSEST METEOROLOGICAL STATION.....	60
FIGURE 132: P ₃ – TEMPERATURE DISTRIBUTION (INSIGHT 360).....	60
FIGURE 133: P ₃ – WIND ROSE SPEED (INSIGHT 360).....	60
FIGURE 134: P ₁ – ENERGY MODEL	61
FIGURE 135: P ₁ – ANALYTICAL SPACES.....	61
FIGURE 136: P ₁ – ANALYTICAL SURFACES	61
FIGURE 137: P ₂ – ENERGY MODEL.....	63
FIGURE 138: P ₂ – ANALYTICAL SPACES.....	63
FIGURE 139: P ₂ – ANALYTICAL SURFACES	63
FIGURE 140: P ₃ – ENERGY MODEL	64
FIGURE 141: P ₃ –ANALYTICAL SPACES	64
FIGURE 142: P ₃ –ANALYTICAL SURFACES.....	64
FIGURE 143: BUILDING TYPE SETTINGS.....	67
FIGURE 144: BUILDING TYPE DATA.....	68

FIGURE 145: BUILDING OPERATING SCHEDULE	68
FIGURE 146: HVAC SYSTEM	68
FIGURE 147:P ₁ INSIGHT ENERGY MODELS	69
FIGURE 148:P ₂ INSIGHT ENERGY MODELS	70
FIGURE 149:P ₃ INSIGHT ENERGY MODELS	70
FIGURE 150: P ₁ – DESIGN ALTERNATIVES	72
FIGURE 151: P ₁ – ENERGY USE INTENSITY OF DESIGN ALTERNATIVES	72
FIGURE 152: P ₁ – DESIGN ALTERNATIVES	72
FIGURE 153: P ₁ – DESIGN ALTERNATIVES	72
FIGURE 154: P ₁ – DESIGN ALTERNATIVES	72
FIGURE 155: P ₁ – DESIGN ALTERNATIVES	72
FIGURE 156: P ₁ - ANNUAL COST AND ANNUAL ENERGY USE INTENSITY OF EACH DESIGN OPTION.....	73
FIGURE 157: P ₂ - ANNUAL COST AND ANNUAL ENERGY USE INTENSITY OF EACH DESIGN OPTION.....	73
FIGURE 158: P ₃ - ANNUAL COST AND ANNUAL ENERGY USE INTENSITY OF EACH DESIGN OPTION.....	73
FIGURE 159: COMPARISON OF ANNUAL ENERGY USE INTENSITY OF EACH DESIGN OPTION FOR EACH MODEL	74
FIGURE 160: COMPARISON OF TOTAL ANNUAL ENERGY USE INTENSITY REDUCTION OF MODELS.....	74
FIGURE 161 P ₁ : INSIGHT 360 FACTOR WIDGETS	84
FIGURE 162: P ₁ – DESIGN ALTERNATIVES	84
FIGURE 163: P ₁ – MODEL COMPARISON - ENERGY USE INTENSITY OF DESIGN ALTERNATIVES	84
FIGURE 164: P ₁ -PV ENERGY POTENTIAL.....	86
FIGURE 165: P ₁ - INSIGHT 360 WIDGETS- OPTIMUM DESIGN.....	86

FIGURE 166: P1- INSIGHT 360 SCENARIO COMPARISON.....	87
FIGURE 167: P1 – DESIGN ALTERNATIVES – DETAILED ELEMENTS	87
FIGURE 168: P1 – MODEL COMPARISON - ENERGY USE INTENSITY OF DESIGN ALTERNATIVES USING DETAILED ELEMENTS.....	87
FIGURE 169 P2: INSIGHT 360 FACTOR WIDGETS	88
FIGURE 170: P2-PV ENERGY POTENTIAL	90
FIGURE 171: P2- INSIGHT 360 WIDGETS- OPTIMUM DESIGN.....	91
FIGURE 172: P2- INSIGHT 360 SCENARIO COMPARISON.....	91
FIGURE 173: P2 – DESIGN ALTERNATIVES (USING DETAILED ELEMENTS)	91
FIGURE 174: P2 – MODEL COMPARISON - ENERGY USE INTENSITY OF DESIGN ALTERNATIVES (USING DETAILED ELEMENTS).....	91
FIGURE 175 P3: INSIGHT 360 FACTOR WIDGETS	93
FIGURE 176: P3-PV ENERGY POTENTIAL	95
FIGURE 177: P3- INSIGHT 360 WIDGETS- OPTIMUM DESIGN.....	95
FIGURE 178: P3A – DESIGN ALTERNATIVES.....	95
FIGURE 179: P3B – DESIGN ALTERNATIVES.....	95
FIGURE 180: P3A – MODEL COMPARISON - ENERGY USE INTENSITY OF DESIGN ALTERNATIVES.....	96
FIGURE 181: P3B – MODEL COMPARISON - ENERGY USE INTENSITY OF DESIGN ALTERNATIVES.....	96
FIGURE 182: P3C – EUI OF DESIGN ALTERNATIVES.....	96
FIGURE 183: P3D – EUI OF DESIGN ALTERNATIVES	96
FIGURE 184: COMPARISON OF EUI OF VARIABLE TRIALS OF DESIGN OPTIONS OF P3 MODELS.....	97

FIGURE 185: COMPARISON OF EUI OF VARIABLE DESIGN OPTIONS OF ALL MODELS WITH ADJUSTED SETTINGS.....	97
FIGURE 186: COMPARISON OF EUI OF VARIABLE DESIGN OPTIONS OF MODELS WITH DEFAULT AND ADJUSTED SETTINGS.....	97
FIGURE 187: INCREASE OF ENERGY PERFORMANCE (%).....	98
FIGURE 188: RELATION OF INVESTMENT COST AND ANNUAL SAVINGS	107
FIGURE 189: P1- OPTION 2 PAYBACK PERIOD	110
FIGURE 190: P1- OPTION 3 PAYBACK PERIOD	112
FIGURE 191: P2- OPTION 2 PAYBACK PERIOD	114
FIGURE 192: P2- OPTION 3 PAYBACK PERIOD	116
FIGURE 193: P3- OPTION 2 PAYBACK PERIOD	118
FIGURE 194: P3- OPTION 3 PAYBACK PERIOD.....	120
FIGURE 195: ALL MODELS- PAYBACK PERIOD	121
FIGURE 196: P2 OPTION 2 TRIAL (NO PRESENT VALUE)- PAYBACK PERIOD	122
FIGURE 197: P2 OPTION 2 & ADDITION OF RENEWABLE ENERGY SOURCES TRIAL (NO PRESENT VALUE)- PAYBACK PERIOD.....	122

Chapter 1

Introduction

1.1. Scope of the Study

The necessity of reducing the global energy consumption had been a common topic of discussion in variable global and European policymaker's panels, giving a specific emphasis to the major energy consuming sectors of which one is the energy consumption of the building sector. This necessity led the European Union to the introduction of several relative policies and directives, with the objective of a gradual improvement of the energy performance of buildings and the reduction of energy consumption.

Since the adoption of the Energy Performance of Buildings Directive (EPBD) (European Parliament, Council of the European Union, 2010) several developments had been implemented towards the European Union member States, applying significant energy saving measures on new and existing buildings. Even though energy consumption of buildings had been into consideration in central and northern European countries since the mid-1970's, in south Europe actual measures were implemented after the adoption of the EPBD, mainly because of the more advantageous climatic conditions, resulting to reduced energy demand for heating and cooling. (Intelligent Energy Europe, 2015)

Despite the progress observed across the Union, the implementation of the EPBD and its effectiveness is still under discussion in some cases (European Commission, Directorate-General for Energy, 2016), one of which being the buildings occupied by social housing recipients. Since the aim of a social housing corporation is to provide affordable housing

solutions to low-income residents, it is obvious that an effort is given in the design and construction of low cost dwellings. Even though their design attempts to not compromise quality, it sometimes comes in contradiction and a reduced emphasis in energy efficiency improvements, which would require a higher initial construction cost and the adoption of advanced technical systems and building services, with the result that the implementation of actual energy efficiency measures been relied on the occupant's will and financial flexibility.

However, it is obvious that the economic conditions of the occupants as well as their lifestyle and education level, sometimes operate as negative factors on understanding the significance of the reduction of energy consumption and the further application of energy efficiency measures, as well as an obstacle to the adoption of energy saving habits.

As stated in the Energy Union Package (European Commission, 2015), the protection of vulnerable energy consumers and the tackle of energy poverty are parts of policy objectives of the European Union. Indeed, as reported by the 2016 study for the ITRE Committee (UGARTE, et al., 2016), energy poverty is observed in all member states, including Cyprus, resulting in an inability of providing basic indoor thermal comfort conditions.

Nevertheless, social-housing dwellings can be considered as a noteworthy case study, to prove the importance and effectiveness of energy saving policies, to promote variable energy saving measures (Fokaides, et al., 2017), or even to create model references for the simulation of proposed enhancement measures in the building sector.

1.2. Objective of the Study

This study aims to simulate variable energy efficiency improvements and evaluate their performance on the building stock of a European member state, Cyprus, and particularly on the dwellings constructed by the national social-housing corporation (Housing Europe, 2010). The study will reclaim the findings of a previous case study (Fokaides, et al., 2017) concerning the analysis of the impact of the EPBD implementation on the building stock of the under-review corporation. The study will assess relative literature on the subject,

focusing mainly in the latest policies in European Union concerning energy consumption in the residential sector and previous case studies on the social-housing sector. Case studies of across Europe will be used as a basis and for comparison of the findings of the study. The methodology to be used for the purposes of the study is described briefly in the third chapter, followed by the work plan to be followed and the anticipated implementation plan in Chapter 4. The main activities of the study are the documentation of the identity of the buildings of the national social-housing corporation of Cyprus, the proposal and simulation of possible improvements and their evaluation according to the requirements of the EPBD. The concluding chapter of the study will try to suggest specific measures in terms of improving the existing buildings and the design characteristics of future projects, in order to comply with the requirements of the future recasts of the EPBD.

Chapter 2

Theoretical Background

2.1. Energy Efficiency on the Residential Sector

Energy Sector consists one of the most significant targets of the European Union for 2020, since it is targeted to reduce the emissions of Greenhouse gases at least 20%, increase the energy efficiency by 20%, and to increase the share of Renewables in the Energy Balance by 20%. Furthermore, those targets are gradually increasing, reaching 40% reduction of GHG emissions and 27% share of Renewables and energy savings by 2030 (European Commission, 2013).

It is also a fact yet that residential sector is one of the key sectors in achieving the targets, since it is responsible for a significant number of GHG emissions, reaching almost 40%, a number that applies not only in EU, but also globally.

The recast of the EPBD (Directive 2010/31/EU) and the Regulation 244/2012 set specific targets in the increase of the energy efficiency and the share of Renewable Energy Sources in the building sector, which introduce the concept of nearly Zero Energy Buildings. Per the EPBD recast, it is an obligation in all member states that all new buildings shall be nearly Zero Energy Buildings by 2020, and by 2018 for public buildings.

The way of achieving those targets is quite challenging, and requires specific measures and practices, to apply the optimum improvements that do not result in an excessive increase of the initial capital cost, but also the ones resulting in the best possible increase of energy efficiency in each member state, based on the specific circumstances and climatic conditions met.

2.2. Social Housing Sector in the European Union

Concerning the social housing sector, even though there is not a common definition of it in the European Union, it holds a significant share of the European building stock, reaching several percentage values across the European countries, which however in some countries reaches 35% (Whitehead & Scanlon, 2007), having also differences in age, typology and percentage. Social housing in Europe is provided in a different regime across the member states, either by rental, subsidies or selling in reasonable prices and procedures, while it has also a variable client group across the member states.

Nevertheless, the aforementioned building stock is provided mainly to the vulnerable parties of the union's population, concerning of low to medium income client groups, letting the validation of the assumption that the social sector client group consist mainly of medium and low-income families, young families, single-parent families, elderly and poor residents, who cannot serve their own housing needs (Whitehead & Scanlon, 2007). This trend however has been changed during the latest years, resulting from the problems arisen due to the economic crisis, letting the client group of the sector accommodate a greater part of the population. Furthermore, in some East European countries the social housing sector had been also a state mechanism to control the demand and supply side of the residential sector, to avoid letting the market act as an integrating social mechanism.

It is worth noted that the demand of the sector is gradually increasing, as a result of increasing dwelling prices and the effects of the global economic crisis. While this fact triggered the existence of long-waiting lists in some major urban areas, some other areas like Germany and northern England face an oversupply of the sector, which led to the introduction of demolition and redesign policies and a scope of increasing density and sustainability.

2.3. Social Housing in Cyprus

Referring to the case of Cyprus, social housing in the country has been provided by the Government by the implementation of various housing schemes focusing on the assistance of various social groups, such as refugees, low and medium income families and vulnerable social groups (Housing Europe, 2010). The main social housing providers in the country are the [Cyprus Land Development Corporation](#) (C.L.D.C.) and the [Housing Finance Corporation](#) (H.F.C.) which were established by the local government to provide respectively building plots or houses and long-term housing loans with lower interest rate for the beneficiaries. The various schemes were targeted mainly to vulnerable social groups composed by displaced families, refugees, low and medium income families, persons living in disadvantaged areas, large families, low-income recipients of public assistance, persons with disabilities.

2.4. Energy Efficiency of Social Housing Dwellings

Social Housing oriented dwellings, are oriented mainly to a specific client group, usually targeted to vulnerable, low or medium income residents, older or young couples. They even sometimes aim to assist the housing or supporting governmental policies when required. Thus, their design is often characterised by units of small to medium size that meet the least minimum requirements, with an effort given of keeping the cost as lower as possible without however compromising quality. Energy performance improvement is sometimes not given the appropriate importance, resulting mainly in the design of buildings that just succeed to comply with the minimum legally binding energy performance requirements. This is either because a better performance building would increase the initial cost or it is let to the owner to decide and apply any interventions.

Even more important is the fact that, in most of the cases, the project life cycle assumed during design stage for cost estimate purposes, ends at the completion of the construction works phase, not taking on mind the operational costs required afterwards by the owner.

However, as reported by FRESH, energy retrofitting of Social Housing in Europe is not supported by a special funding, which forms a significant barrier in its promotion. (MILIN, et al., 2011)

2.5. Building Information Modelling

During conventional design, using two-dimensional software, a lack of interconnection and integration of multi-discipline designers could possibly exist, requiring careful collaboration between the team members. Computational models such as Building Information Modelling is capable to minimize possible issues during information exchange, since it supports data collaboration, but it can also form a key aspect in the analysis and approximation of the energy consumption of new or existing dwellings. A BIM tool can be employed not only for the estimation of accurate building information and estimate quantities of materials and elements but is also capable in projecting the energy performance of buildings and the comparison of improvements. (Habibi, 2017)

According to Autodesk (Autodesk, n.d.), BIM is a process that gives an intelligent three-dimensional model, capable to assist designers in a more efficient design, construction and management of a project. Furthermore, BIM and related plug-ins can assist in the visualization of essential performance parameters and factors in the energy performance of a project. As stated by the Autodesk, results on energy performance of a model are extracted through a web-based service, which collects data from the building model, the building use and regionalized databases concerning local weather conditions. (Autodesk, 2010)

Chapter 3

Methodology

The main objective of this study is to create models of the identity of buildings constructed by CLDC, propose specific energy efficiency improvement measures and evaluate their performance. For the purposes of the study, the thermal and structural characteristics of 19 existing dwellings and 4 dwellings been at the design stage will be employed and modelled. The existing dwellings belong to three separate categories, classified according to their construction period, based on variable building characteristics. The Period 1, 2 and 3 were considered from 1984 to 1999, from 2000 to 2007 and from 2007 onwards respectively. The dwellings been at the design stage have similar characteristics to the ones at Period 3, with minor improvements, however been yet at pre-construction stage allowing for the opportunity for more significant measures.

The software tool employed for the purposes of the project is the BIM capable Autodesk Revit 2017 for the modelling purposes and for the simulation and evaluation of the proposed measures the Plug-In Insight 360. The software and the required plug-in have been tested during this proposal stage by creating the model of the identity of a test-building and it was evaluated as satisfactory for the purposes of the study.

The results of the proposed measures will then be evaluated and documented according to their performance magnitude with the scope of defining specific typical cases for the improvement of the energy efficiency of the dwellings of each period, and improved models for future designs.

Chapter 4

Analysis of Models

4.1. Preparation of Models

Prior to the analysis and the implementation of any enhancements, the models of the selected dwellings had to be prepared. The models are based on dwelling types that represent the typical residence types that were constructed by the organisation, at different chronological periods, as categorized in a previous study. (Fokaides, et al., 2017)

The procedure followed for the preparation of the models consisted of the following steps:

- Preparation of Building Information Models (BIM) in Revit, according to the existing architectural plans.
- Identification of their existing energy performance
- Identification of significant factors and parameters in increasing their efficiency and performance, and reducing their annual energy consumption
- Application and evaluation of enhancement measures in improving their energy performance

4.1.1 Elements Used for the Simulation

The elements used for the simulation of the models are illustrated in the following figures. Further details are provided on the relative sections and tables for each model:

Walls

	Heat Transfer Coefficient (U)	2.0000 W/(m ² ·K)
	Thermal Resistance (R)	0.5000 (m ² ·K)/W
	Thermal mass	18.50 kJ/K

Figure 1: Interior Brick Wall 100mm

	Heat Transfer Coefficient (U)	1.3333 W/(m ² ·K)
	Thermal Resistance (R)	0.7500 (m ² ·K)/W
	Thermal mass	32.00 kJ/K

Figure 2: Interior Brick wall 200mm

	Heat Transfer Coefficient (U)	1.4493 W/(m ² ·K)
	Thermal Resistance (R)	0.6900 (m ² ·K)/W
	Thermal mass	32.00 kJ/K

Figure 3: Exterior Brick wall 200mm

	Heat Transfer Coefficient (U)	7.6923 W/(m ² ·K)
	Thermal Resistance (R)	0.1300 (m ² ·K)/W
	Thermal mass	33.07 kJ/K

Figure 4: Interior Shear Wall 200mm

	Heat Transfer Coefficient (U)	1.1429 W/(m ² ·K)
	Thermal Resistance (R)	0.8750 (m ² ·K)/W
	Thermal mass	38.75 kJ/K

Figure 5: Interior Brick Wall 250mm

	Heat Transfer Coefficient (U)	0.3934 W/(m ² ·K)
	Thermal Resistance (R)	2.5417 (m ² ·K)/W
	Thermal mass	38.93 kJ/K

Figure 6: Interior Brick Wall 250mm +5cm External Insulation

	Heat Transfer Coefficient (U)	0.2376 W/(m ² ·K)
	Thermal Resistance (R)	4.2083 (m ² ·K)/W
	Thermal mass	39.10 kJ/K

Figure 7: Interior Brick Wall 250mm +10cm External Insulation

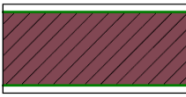
	Heat Transfer Coefficient (U)	0.4030 W/(m ² ·K)
	Thermal Resistance (R)	2.4817 (m ² ·K)/W
	Thermal mass	38.93 kJ/K

Figure 8: Exterior Brick Wall 250mm

	Heat Transfer Coefficient (U)	0.4030 W/(m ² ·K)
	Thermal Resistance (R)	2.4817 (m ² ·K)/W
	Thermal mass	38.93 kJ/K

Figure 9: Exterior Brick Wall 250mm +5cm External Insulation

	Heat Transfer Coefficient (U)	0.2411 W/(m ² ·K)
	Thermal Resistance (R)	4.1483 (m ² ·K)/W
	Thermal mass	39.10 kJ/K

Figure 10: Exterior Brick Wall 250mm +10cm External Insulation

	Heat Transfer Coefficient (U)	0.2295 W/(m ² ·K)
	Thermal Resistance (R)	4.3567 (m ² ·K)/W
	Thermal mass	32.18 kJ/K

Figure 11: Exterior Brick Wall 250mm with gap + 5cm External Insulation

	Heat Transfer Coefficient (U)	0.2264 W/(m ² ·K)
	Thermal Resistance (R)	4.4167 (m ² ·K)/W
	Thermal mass	32.18 kJ/K

Figure 12: Interior Brick Wall 250mm with gap + 5cm External Insulation

	Heat Transfer Coefficient (U)	0.1660 W/(m ² ·K)
	Thermal Resistance (R)	6.0233 (m ² ·K)/W
	Thermal mass	32.36 kJ/K

Figure 13: Exterior Brick Wall 250mm with gap + 10cm External Insulation

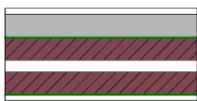
	Heat Transfer Coefficient (U)	0.1644 W/(m ² ·K)
	Thermal Resistance (R)	6.0833 (m ² ·K)/W
	Thermal mass	32.36 kJ/K

Figure 14: Interior Brick Wall 250mm with gap + 10cm External Insulation

	Heat Transfer Coefficient (U)	0.3636 W/(m ² ·K)
	Thermal Resistance (R)	2.7500 (m ² ·K)/W
	Thermal mass	32.00 kJ/K

Figure 15: Interior Brick Wall 250mm with gap

	Heat Transfer Coefficient (U)	0.3717 W/(m ² ·K)
	Thermal Resistance (R)	2.6900 (m ² ·K)/W
	Thermal mass	32.00 kJ/K

Figure 16: Exterior Brick Wall 250mm with gap

Floors

	Heat Transfer Coefficient (U)	2.7438 W/(m ² ·K)
	Thermal Resistance (R)	0.3645 (m ² ·K)/W
	Thermal mass	39.75 kJ/K

Figure 17: Exposed Floor (P1-P2)

	Heat Transfer Coefficient (U)	2.7438 W/(m ² ·K)
	Thermal Resistance (R)	0.3645 (m ² ·K)/W
	Thermal mass	39.75 kJ/K

Figure 18: Interior Floor (P1-P2)

	Heat Transfer Coefficient (U)	1.9543 W/(m ² ·K)
	Thermal Resistance (R)	0.5117 (m ² ·K)/W
	Thermal mass	91.60 kJ/K

Figure 19: Exposed Floor (P3)

	Heat Transfer Coefficient (U)	2.2436 W/(m ² ·K)
	Thermal Resistance (R)	0.4457 (m ² ·K)/W
	Thermal mass	56.20 kJ/K

Figure 20: Interior Floor (P3)

Roofs

	Heat Transfer Coefficient (U)	4.1671 W/(m ² ·K)
	Thermal Resistance (R)	0.2400 (m ² ·K)/W
	Thermal mass	27.50 kJ/K

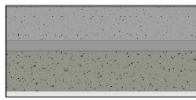
Figure 21: Roof (P1-P2)

	Heat Transfer Coefficient (U)	0.4056 W/(m ² ·K)
	Thermal Resistance (R)	2.4657 (m ² ·K)/W
	Thermal mass	37.50 kJ/K

Figure 22: Roof (P1-P2) + 5cm External Insulation

	Heat Transfer Coefficient (U)	0.2155 W/(m ² ·K)
	Thermal Resistance (R)	4.6397 (m ² ·K)/W
	Thermal mass	37.68 kJ/K

Figure 23: Roof (P1-P2) + 10cm External Insulation



Heat Transfer Coefficient (U)	0.4954 W/(m ² ·K)
Thermal Resistance (R)	2.0184 (m ² ·K)/W
Thermal mass	49.91 kJ/K

Figure 24: Roof (P3)



Heat Transfer Coefficient (U)	0.5106 W/(m ² ·K)
Thermal Resistance (R)	1.9585 (m ² ·K)/W
Thermal mass	37.50 kJ/K

Figure 25: Roof (P3) + 5cm External Insulation



Heat Transfer Coefficient (U)	0.2758 W/(m ² ·K)
Thermal Resistance (R)	3.6252 (m ² ·K)/W
Thermal mass	37.68 kJ/K

Figure 26: Roof (P3) + 10cm External Insulation

4.1.2 Model of Category P₁

The first model consisted of a typical 115m² three-bedroom single family residence, located in Nicosia meteorological zone 2, in Cyprus. The dwelling belongs to the first period (P₁), that took into consideration buildings constructed from 1984 to 1999. The type of the dwelling is a semi-detached two-storey structure, that follows the construction structural and thermal characteristics applied during that chronological period. In particular, the building envelope is composed by common 20cm bricks, reinforced concrete structural elements and reinforced concrete floors and roof, all without any insulation applied. Floors are finished by screed and ceramic tiles and roofs by screed and roofing felt (bituminous membrane waterproofing) and an additional wooden roof structure with tiles. Openings of the building consist of single glazed windows made of aluminium and wooden doors. The geometry of the building is illustrated at the figures below. (Figure 27- Figure 46)

The ground floor level of the building is at an altitude of +100.14m and the height of each floor is around 3.00m. The rooms located at the ground floor are the kitchen, the living room, the WC and the staircase which connects it to the first floor which consists of a corridor, three bedrooms and two bathrooms.

Table 1: Category P₁ – Floors / Levels

Nº	Name	Level (Altitude) (m)	Floor Height (m)
1	Ground Floor	100.14	3.10
2	First Floor	103.24	3.00
3	Roof	106.24	

Table 2: Category P₁ - Rooms

No	Name	Level	Area (m²)
1	Kitchen	Ground Floor	21 m ²
2	Living Room	Ground Floor	31 m ²
3	Staircase	Ground Floor	2 m ²
4	WC	Ground Floor	2 m ²
5	Bedroom 3	First Floor	13 m ²

6	Bedroom 2	First Floor	12 m ²
7	Bathroom 2	First Floor	4 m ²
8	Bedroom 1	First Floor	15 m ²
9	Bathroom 1	First Floor	6 m ²
10	Staircase – Corridor	First Floor	9 m ²

Total Area (m²)

115 m²

P1: Plan Views

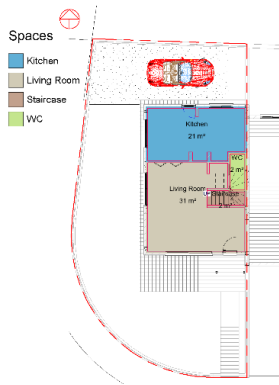


Figure 27: P1 -Ground Floor

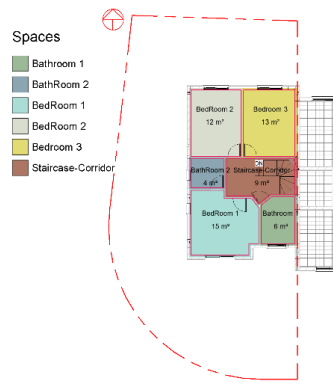


Figure 28: P1 -First Floor

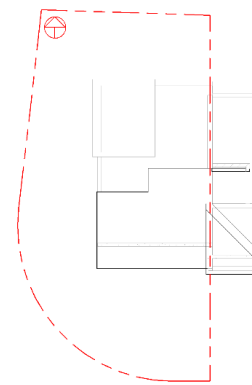


Figure 29: P1 - Roof Plan

P1: 3D Views

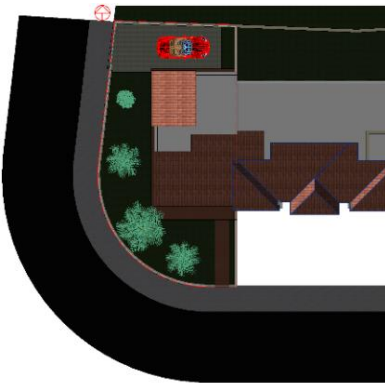


Figure 30: P1 - 3D Views



Figure 31: P1 - 3D Views



Figure 32: P1 - 3D Views

P1 - Elevations

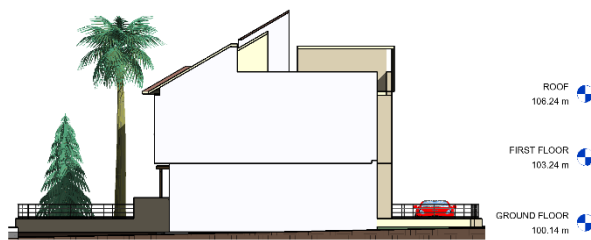


Figure 33: P1 - East Elevation



Figure 34: P1 - North Elevation

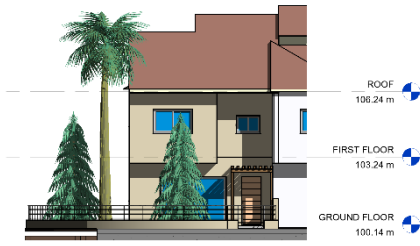


Figure 35: P1 - South Elevation

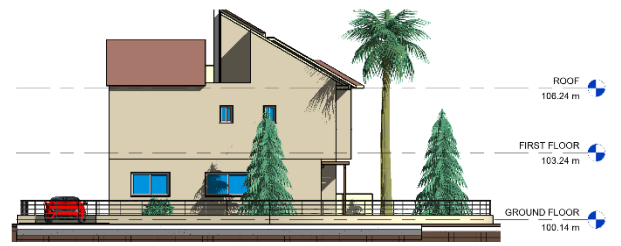


Figure 36: P1 - West Elevation

P₁: Sections

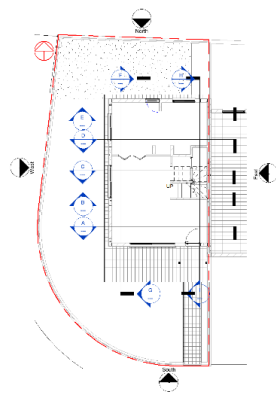


Figure 37: Sections (layout)

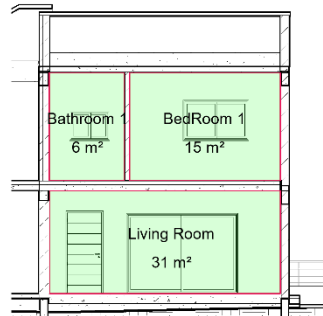


Figure 38: P₁ - Section A



Figure 39: P₁ - Section B



Figure 40: P₁ - Section C

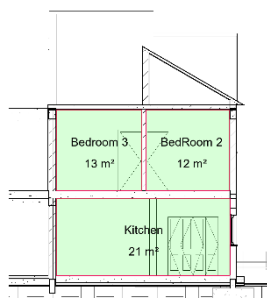


Figure 41: P₁ - Section D

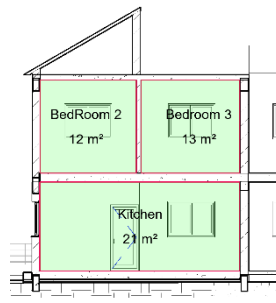


Figure 42: P₁ - Section E

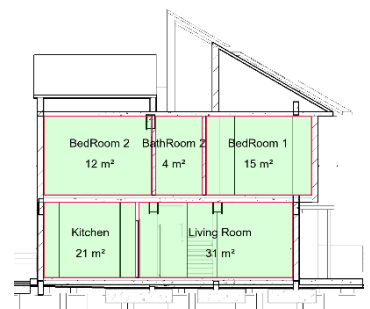


Figure 43: P₁ - Section F

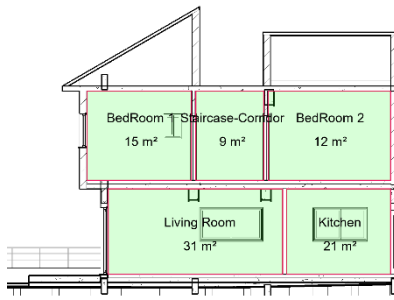


Figure 44: P1 – Section G

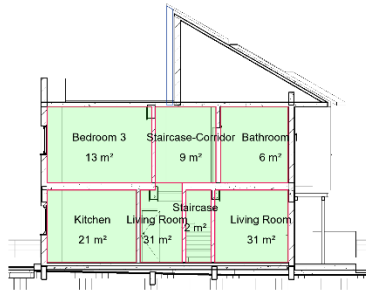


Figure 45: P1 – Section H

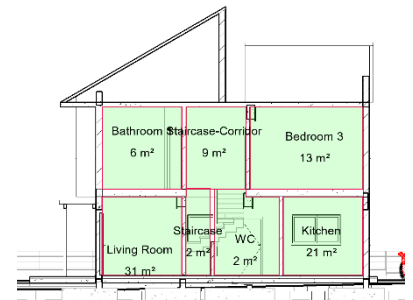


Figure 46: P1 – Section I

4.1.3 Model of Category P2

The second model consisted of a typical 94m² three-bedroom single family residence of the second period (P₂), which is formed by buildings constructed from 2000-2008. It is also located in Nicosia meteorological zone 2, in Cyprus and its type can be characterised as a semi-detached two-storey structure. The construction structural and thermal characteristics applied during that chronological period and to the selected building are similar to the ones of the first period (P₁) and can be described as having an envelope formed by common 20cm bricks, non-insulated reinforced concrete structural elements and reinforced concrete floors and roof. Floors are finished by screed and ceramic tiles and roofs by screed and roofing felt (bituminous membrane waterproofing) however without the additional wooden roof structure with tiles. However, openings of the building of that period are made by double glazed windows and doors made of aluminium. Improvements were also applied to the architectural design, in comparison to the first period. The geometry of the selected building is illustrated at the following figures. (Figure 47 - Figure 85 below)

The ground floor level of the building is at an altitude of +102.95m and the height of each floor is around 2.90m (Table 3). The rooms located at the ground floor are the kitchen, the living room, the WC and the staircase which connects it to the first floor which consists of a corridor, three bedrooms and one bathroom.

Table 3: Category P2 – Floors / Levels

No	Name	Level (Altitude) (m)	Floor Height (m)
1	Ground Floor	102.95	2.95
2	First Floor	105.90	2.83
3	Roof	108.73	

Table 4: Category P2 - Rooms

Number	Name	Level	Area (m²)
1	Living Room	Ground Floor	26 m ²
2	Kitchen	Ground Floor	17 m ²
3	WC	Ground Floor	2 m ²
4	Staircase	Ground Floor	3 m ²
5	Bedroom 1	First Floor	12 m ²
6	Staircase	First Floor	4 m ²
7	Bedroom 2	First Floor	9 m ²
8	Bedroom 3	First Floor	13 m ²

9	Bathroom	First Floor	5 m ²
10	Corridor	First Floor	3 m ²
Total Area (m2)			94 m²

P₂: Plan Views

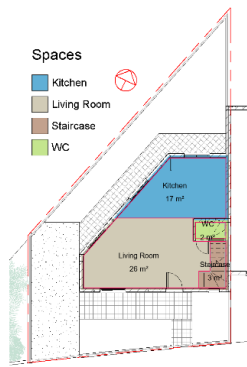


Figure 47: P₂ -Ground Floor

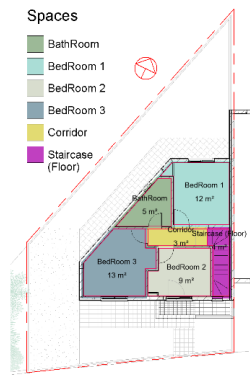


Figure 48: P₂ - First Floor

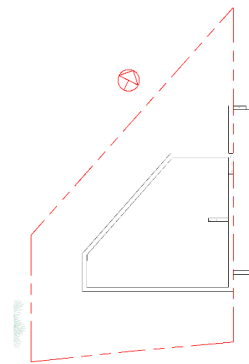


Figure 49: P₂ - Roof

P₂: 3D Views



Figure 50: P₂ – 3D Views



Figure 51: P₂ – 3D Views



Figure 52: P₂ – 3D Views

P₂ – Elevations

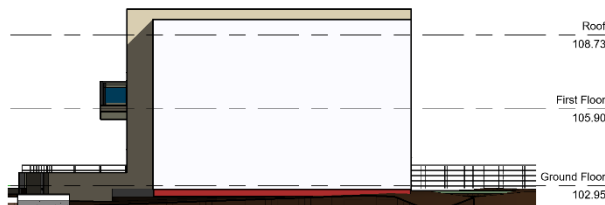


Figure 53: P₂ – East Elevation



Figure 54: P₂ – North Elevation



Figure 55: P₂ – South Elevation



Figure 56: P₂ – West Elevation

P₂ - Sections

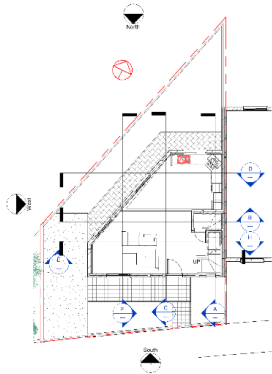


Figure 57: Sections Layout

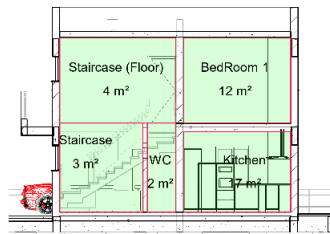


Figure 58: P₂ – Section A-A

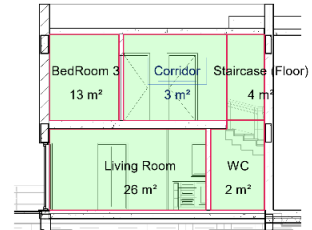


Figure 59: P₂ – Section B-B

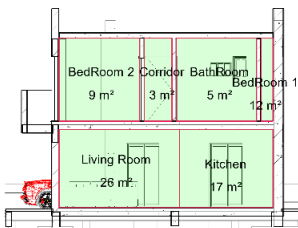


Figure 60: P₂ – Section C-C

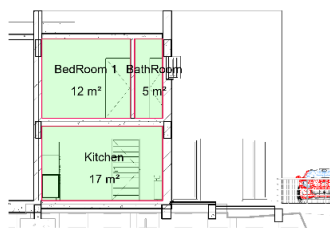


Figure 61: P₂ – Section D-D

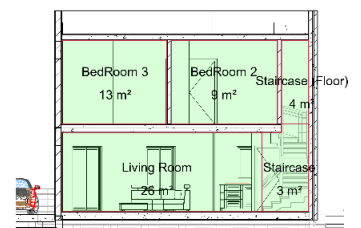


Figure 62: P₂ – Section E-E

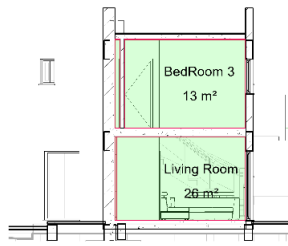


Figure 63: P₂ – Section F-F

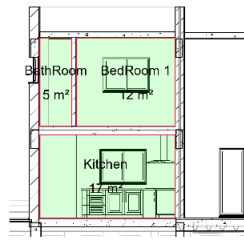


Figure 64: P₂ – Section G-G

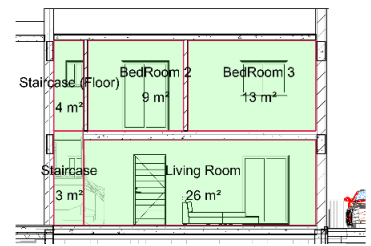


Figure 65: P₂ – Section H-H

4.1.4 Model of Category P₃

The third model consisted also of a typical three-bedroom single family residence of an area equal to 86m² that belongs to the third period (P₃), which concerns buildings constructed from 2009-2014. It is also located in Nicosia meteorological zone 2, in Cyprus and its type can be characterised as a semi-detached two-storey structure. The construction structural and thermal characteristics applied during that chronological period and to the selected building follow the minimum requirements for the energy performance of buildings directive of that time.

Particularly, the building envelope consists of 25cm thermal bricks, insulated reinforced concrete structural elements and reinforced concrete insulated floors and roof. Floors are finished by screed and ceramic tiles and roofs by thermal insulation, screed and roofing felt (bituminous membrane waterproofing).

Furthermore, exterior openings of the building are made by double glazed low-e windows and doors made of aluminium, and a solid wood main entrance door. Improvements were also applied to the architectural design. The geometry of the selected building is illustrated at the following figures. (Figure 66- Figure 85)

The ground floor level of the building is located at an altitude of +252.90m and the height of each floor is around 2.90m (Table 5). The rooms located at the ground floor are the kitchen, the living room, the WC a storage place below the staircase, and the staircase which connects it to the first floor which consists of a corridor, three bedrooms and one bathroom.

Table 5: Category P3 – Floors / Levels

No	Name	Level (Altitude) (m)	Floor Height (m)
1	Ground Floor	252.90	3.03
2	First Floor	255.93	2.78
3	Roof	258.71	

Table 6: Category P2 - Rooms

Number	Name	Level	Area (m²)
1	Living Room	Ground Floor	27 m ²
2	WC	Ground Floor	2 m ²
3	Kitchen	Ground Floor	9 m ²
4	Storage	Ground Floor	4 m ²
5	Bedroom 1	First Floor	10 m ²
6	Bedroom 2	First Floor	10 m ²

7	Bedroom 3	First Floor	10 m ²
8	Bathroom	First Floor	5 m ²
9	Staircase	First Floor	4 m ²
10	Corridor	First Floor	5 m ²
Total Area (m2)			86 m²

P₃: Plan Views



Figure 66: P₃-Ground Floor

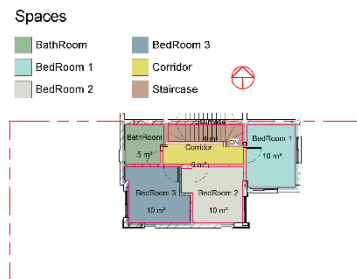


Figure 67: P₃ -Ground Floor

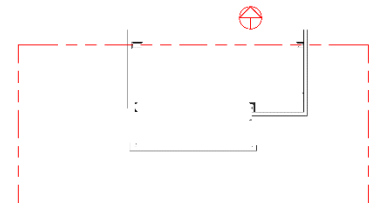


Figure 68: P₃ -Ground Floor

P3: 3D Views



Figure 69: P2 – 3D Views



Figure 70: P2 – 3D Views



Figure 71: P2 – 3D Views

P3 – Elevations



Figure 72: P3 – East Elevation

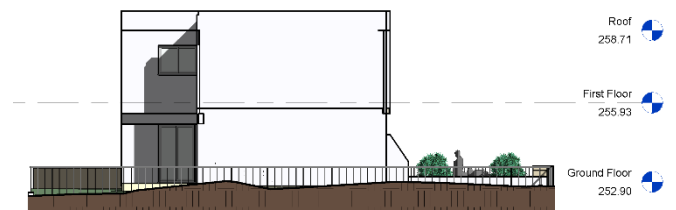


Figure 73: P3 – North Elevation

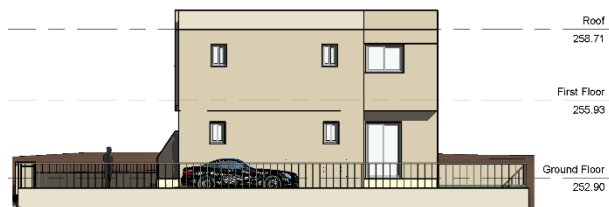


Figure 74: P2 – South Elevation



Figure 75: P2 – West Elevation

P₃ - Sections

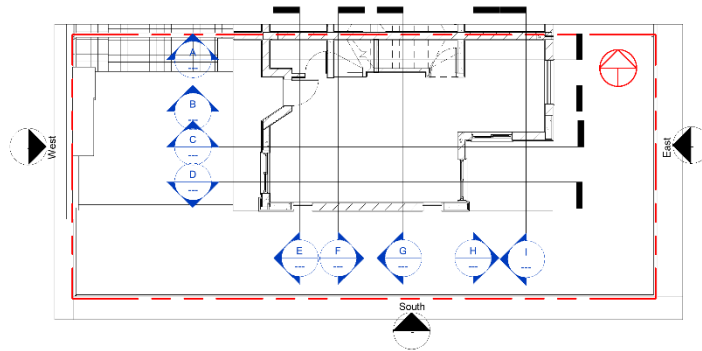


Figure 76: Sections (layout)

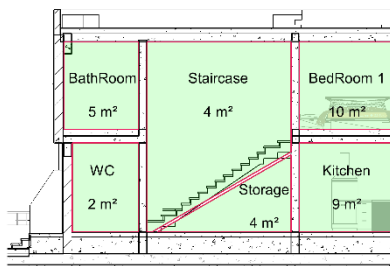


Figure 77: P₃ - Section A-A

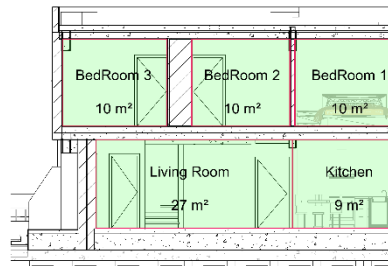


Figure 78: P₃ - Section B-B

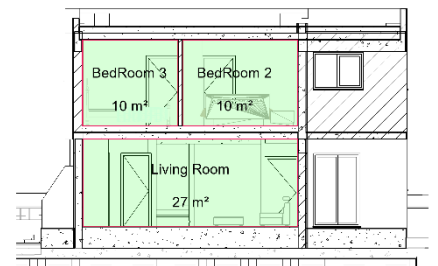


Figure 79: P₃ - Section C-C

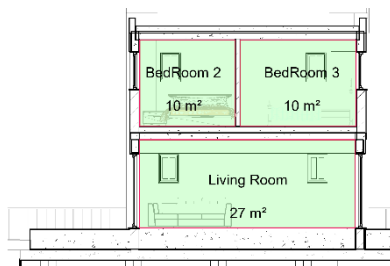


Figure 80: P₃ - Section D-D

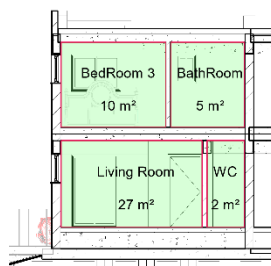


Figure 81: P₃ - Section E-E

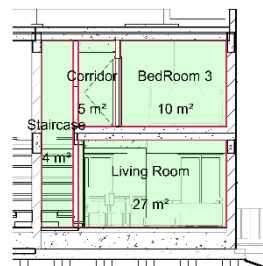


Figure 82: P₃ - Section F-F

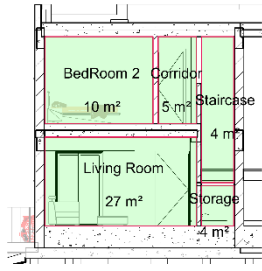


Figure 83: P₃ – Section G-G

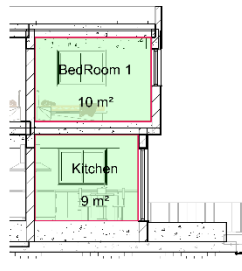


Figure 84: P₃ – Section H-H



Figure 85: P₃ – Section I-I

4.2. Existing Thermal Characteristics

Prior to the preparation of the detailed model of each dwelling, thermal properties were assigned to each material used, so that a decent thermal resistance of the elements would be achieved, as close as possible to the real construction characteristics.

According to the construction characteristics, and the information acquired from the architectural drawings of each dwelling, a topography surface was drawn by placing elevation points, aiming to simulate the ground (soil) behaviour. The surface was then graded at the place that the building would be accommodated, and a concrete building pad was placed, below the foundation elements.

The exact orientation of each model and the geographic location of the project were specified. All information is listed in the tables below.

4.2.1 Existing Characteristics of Model P₁

The aforementioned first model was simulated by using structural columns, structural framing and structural foundations elements of reinforced concrete, while the masonry infill panels were modelled by using walls made of common bricks. Windows made of aluminium and wooden doors dimensions were drawn according to the building's drawings. Their analytical construction was defined as *single glazing residential* for the windows, *solid core wood* for the main exterior entrance and *hollow core-wood storm* for the interior doors, based on the materials available by the software. (Table 7, Table 8)

4.2.2 Existing Characteristics of Model P₂

Concerning the dwelling of the second period, the model was created by using similar elements with the ones used for the previous model, for the simulation of the building shell.

In particular, the elements used consisted of reinforced concrete columns, framing and foundations and walls made of common bricks. Although the building shell seems identical to the one used at the previous model, minor improvements were applied in the architectural design and the openings used. That said, the analytical construction of the aluminium sliding windows was defined as *double glazing residential*, while *solid core wood* was used for the main exterior entrance and *hollow core-wood storm* for the interior doors. The size of the openings and their location were drawn according to the architectural drawings.

4.2.3 Existing Characteristics of Model P₃

Significant improvements were observed at the dwelling of the third period, since its design and construction took into consideration the requirements of the regulation for the minimum requirements for the energy performance of buildings.

Indeed, the simulation was created by using structural elements (columns and beams) of reinforced concrete with the addition of 3cm external insulation at their exposed surfaces, while the walls were constructed by using 250 thermal insulating bricks. Furthermore, the ground floor consisted of a 500mm raft foundation, coupled with a 120mm screed layer below the floor tiles. Similarly, a 120mm screed layer was added below the floor tiles and above the reinforced concrete slab. Concerning the building's roof, apart from the slab, the screed and the waterproofing, an additional layer of 50mm extruded polystyrene was placed above the slab to improve the resistance of the element. In addition, low-e glazing was added, so the analytical construction of the aluminium sliding windows was defined as *Low-E double glazing – domestic*. *Solid core wood* remained the material used for the main exterior entrance and *hollow core-wood storm* for the interior doors. The size of the openings and their location were drawn according to the architectural drawings.

Table 7: Category P₁ – Simulation Assumptions/ Location

Simulation Assumptions/ Location					
Location	Nicosia, Cyprus				
Geographic Location	35.1884117126465, 33.3814010620117	N/S	16.4288	E/W	28.0948
Orientation	angle of model to true north: 0.00°				

Table 8: Category P₁ – Simulation Assumptions/ Elements

Elements						
Structural Members	Type	Material	Thermal Conductivity (λ) [W/(mK)]	Thermal Mass [kJ/K]	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U-value) [W/m ² K]
	Columns, Variable size	Reinforced Concrete			2.5000	Not Applicable in the Software
	Framing (Beams), Variable size					
	Footings					
	Building Pad	Concrete 100mm	1.35	14.04	0.0741	13.50

Walls					
No	Type	Function	Thermal Mass [kJ/K]	Thermal Resistance (R) [m²K/W]	Heat Transfer Coefficient (U-value) [W/m²K]
1	Brick Wall 200mm	Exterior	32.00	0.69	1.4493
2	Double Brick Wall 250mm (with gap)	Exterior	32.00	2.69	0.3717
3	Brick Wall 200mm	Interior	32.00	0.75	1.3333
4	Brick Wall 100mm	Interior	18.50	0.5000	2.0000
5	Double Brick Wall 250mm (with gap)	Interior	32.00	2.75	0.3636
Floors					

Type / Function	Level	Description	Thermal Mass [kJ/K]	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U-Value) [W/m ² K]
Exposed interior floor	Ground Floor	150mm R.C. Slab, 120mm Floor (Screed and Tiles)	38.26	0.3495	2.8616
Interior Floor	First Floor	150mm R.C. Slab, 120mm Floor (Screed and Tiles)	39.75	0.3645	2.7438

Roof						
Exposed Roof	Roof	R.C. Slab/Roof	23.28	0.2178	4.5924	

	Inclined Roof	Roof	R.C. Roof Waterproofing, Tiles	14.12	0.1104	9.0553
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Windows

Type	Dimensions (mm)	Function	Solar Heat Gain Coefficient	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U-Value) [W/m ² K]
Sliding Windows (aluminium)	Variable: 1500 X 1500 1800 X 1500 2100 X 1500 1100 X 800 600 X 800	Exterior	0.86	0.1743	5.7361

Doors

Type	Dimensions (mm)	Function / Description	Solar Heat Gain Coefficient	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U-Value) [W/m ² K]
Sliding Doors	3000 X 2200	Exterior / (aluminium)	0.86	0.1743	5.7361
Main Entrance	900 X 2200	Exterior / (Swing Door, Solid Core Wood)		0.3829	2.6119
Bifold four Panel		Interior / Bi-folding (Hollow Core Wood)		0.5337	1.8737

	Interior Doors	Variable 762 x 2134 813 x 2134mm	Interior / Swing Doors (Hollow Core – Wood Storm)		0.5337	1.8737
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Table 9: Category P₂ – Simulation Assumptions/ Location

Simulation Assumptions/ Location					
Location	Nicosia, Cyprus				
Geographic Location	35.0729293823242, 33.3193893432617				
Orientation	angle of model to true north: 334.26°	N/S	16.4288	E/W	28.0948

Table 10: Category P₂ – Simulation Assumptions/ Elements

Elements						
Structural Members	Type	Material	Thermal Conductivity (λ) [W/(mK)]	Thermal Mass [kJ/K]	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U-Value) [W/m ² K]
	Columns, Variable size	Reinforced Concrete	2.5000	Not Applicable in the Software		
	Framing (Beams), Variable size					
	Footings					
	Building Pad	Concrete 300mm	1.35	42.79	0.2258	4.4291

Walls

No	Type	Function	Thermal Mass [kJ/K]	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U-Value) [W/m ² K]
1	Brick Wall 200mm	Exterior	32.00	0.69	1.4493
2	Double Brick Wall 250mm (with gap)	Exterior	32.00	2.69	0.3717
3	Brick Wall 200mm	Interior	32.00	0.75	1.3333
4	Brick Wall 100mm	Interior	18.50	0.5000	2.0000
5	Double Brick Wall 250mm (with gap)	Interior	32.00	2.75	0.3636

Floors

Type / Function	Level	Description	Thermal Mass [kJ/K]	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U-Value) [W/m ² K]
Exposed interior floor	Ground Floor	150mm R.C. Slab and 120mm Floor (Screed and Tiles)	38.26	0.3495	2.8616
Interior Floor	First Floor	150mm R.C. Slab, 120mm Floor (Screed and Tiles)	39.75	0.3645	2.7438

Roof

	Exposed Roof	Roof	R.C. Slab/Roof, Thin Screed layer, Waterproofing (200mm)	27.50	0.2422	4.1286
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Windows

Type	Dimensions (mm)	Function / Description	Solar Heat Gain Coefficient	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U-Value) [W/m ² K]
Sliding Windows	Variable: 1500 X 1500 600 X 800	Exterior / Aluminium	0.76	0.3196	3.1292

Doors

Type	Dimensions (mm)	Function / Description	Solar Heat Gain Coefficient	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U-Value) [W/m ² K]
Sliding Doors	1500 X 2200	Exterior / (aluminium)	0.76	0.3196	3.1292
Main Entrance	988 X 2200	Exterior / (Swing Door, Solid Core Wood)		0.59	1.6949
Interior Doors	Variable 762 x 2134 813 x 2134mm 864 x 2134mm	Interior / Swing Doors (Hollow Core – Wood Storm)		0.5337	1.8737

Table 11: Category P₃ – Simulation Assumptions/ Location

Simulation Assumptions

Location	Nicosia, Cyprus				
Geographic Location	35.1665000915527, 33.2069435119629				
Orientation	angle of model to true north: 0.00°	N/S	0.00	E/W	0.00

Table 12: Category P₃ – Simulation Assumptions/ Elements

Elements						
Structural Members	Type	Material	Thermal Conductivity (λ) [W/(mK)]	Thermal Mass [kJ/K]	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U-Value) [W/m ² K]
	Columns, Variable size	Reinforced Concrete	2.5000	Not Applicable in the Software		
	Framing (Beams), Variable size					
	Insulation applied at the External site of columns and Frames	30mm Expanded Polystyrene	0.03	2.60	1.0650	0.9390
	Building Pad	Concrete 100mm	1.35	14.04	0.0741	13.50

Walls

No	Type	Function	Thermal Mass [kJ/K]	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U value) [W/m ² K]
1	Brick Wall 250mm	Exterior	38.75	0.8150	1.2270
2	Brick Wall 250mm	Interior	38.75	0.8750	1.1429
3	Shear Wall 200mm	Interior	33.07	0.33	3.0303
4	Brick Wall 100mm	Interior	18.50	0.5000	2.0000
5	Brick Wall 200mm	Interior	32.00	0.55	1.8182

Floors

Type / Function	Level	Description	Thermal Mass [kJ/K]	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U-Value) [W/m ² K]
Exposed interior floor	Ground Floor	500mm R.C. Raft Foundation and 150mm Floor (Screed and Tiles)	91.60	0.5117	1.9543
Interior Floor	First Floor	180mm R.C. Slab, 180mm Floor (Screed and Tiles)	56.20	0.4457	2.2436
Roof					
Exposed Roof	Roof	180mm R.C. Slab, 200mm Roof (Waterproofing, Expanded Polysterene 50mm, 150mm Screed)	49.91	2.0184	0.4954
Windows					

Type	Dimensions (mm)	Function / Description	Solar Heat Gain Coefficient	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U value) [W/m ² K]
Sliding Windows	Variable: 1500 X 1100 600 X 550	Exterior / Aluminium	0.65	0.4515	2.2147

Doors					
Type	Dimensions (mm)	Function / Description	Solar Heat Gain Coefficient	Thermal Resistance (R) [m ² K/W]	Heat Transfer Coefficient (U-value) [W/m ² K]

	Sliding Doors	1400 X 2200	Exterior / (aluminium)	0.65	0.4515	2.2147
	Main Entrance	988 X 2200	Exterior / (Swing Door, Solid Core Wood)		0.59	1.6949
	Interior Doors	Variable 762 x 2134 864 x 2134mm	Interior / Swing Doors (Hollow Core - Wood Storm)		0.5337	1.8737

4.3. Weather Data

Based on the location set for each model, the following data represent the weather data of the location, according to data of the closest meteorological station. Noteworthy, all buildings are located in Nicosia, which belongs to the meteorological zone 2 of Cyprus.

The main meteorological data of the area are presented in the following figures for each model.

4.3.1 Category P₁

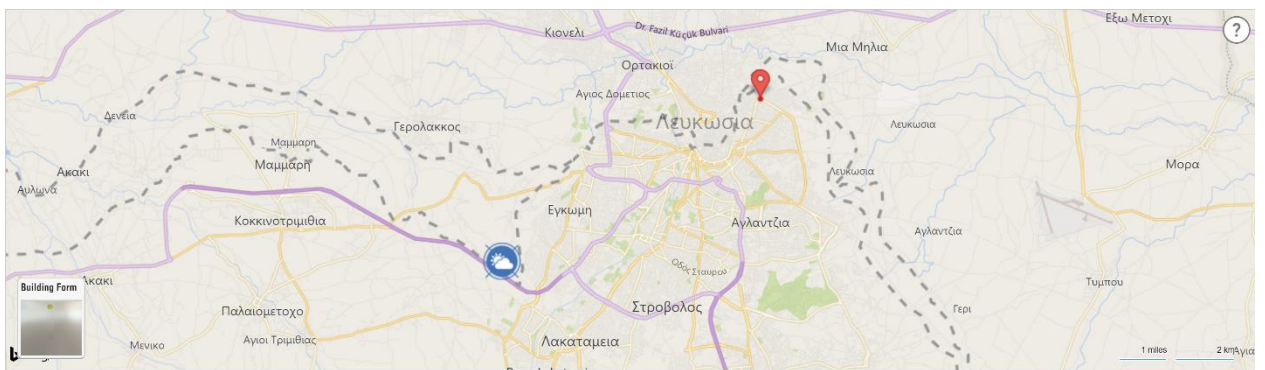


Figure 86: P₁ – Location – Closest Meteorological Station

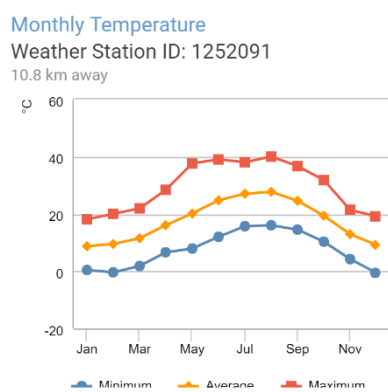


Figure 87: P₁ – Temperature Distribution (Insight 360)

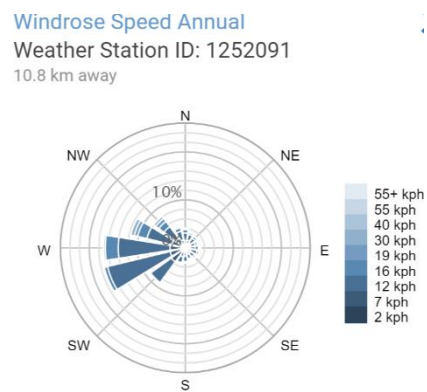


Figure 88: P₁ – Windrose Speed (Insight 360)


Weather Station: [GBS_06M12_18_112222](#) 
 Distance to your project 4.3 mi (6.9 km)
 Latitude = 35.1333 , Longitude = 33.4167

Figure 89: P1 –Green Building Studio Weather Station

Table 13: P1: Weather Summary

Cooling Degree Day		Heating Degree Day	
Threshold	Value	Threshold	Value
18.3 °C	1105	18.3 °C	1191
21.1 °C	676	15.6 °C	694
23.9 °C	334	12.8 °C	313
26.7 °C	88	10 °C	97

Annual Design Conditions				
Threshold	Cooling		Heating	
	Dry Bulb(°C)	MCWB(°C)	Dry Bulb(°C)	MCWB(°C)
0.1 %	39.0	21.7	-0.1	-1.2
0.2 %	38.3	20.7	0.1	-1.1
0.4 %	37.5	20.6	0.7	-0.5
0.5 %	37.4	20.5	1.3	-0.4
1 %	36.7	20.9	2.1	0.8
2 %	35.8	21.0	3.3	1.6
2.5 %	35.3	20.6	3.9	2.6
5 %	33.7	20.3	5.1	3.7

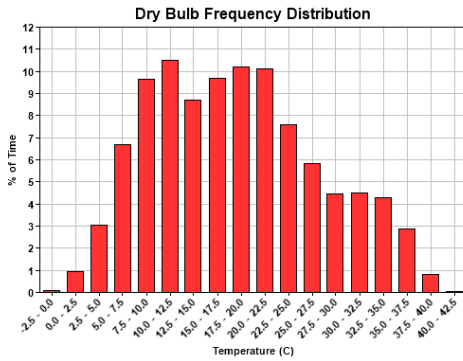


Figure 90: P1–Dry Bulb Frequency Distribution

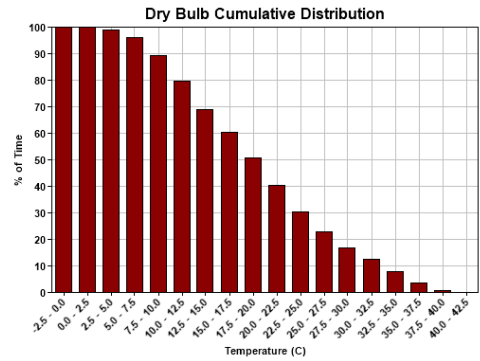


Figure 91: P1–Dry Bulb Cumulative Distribution

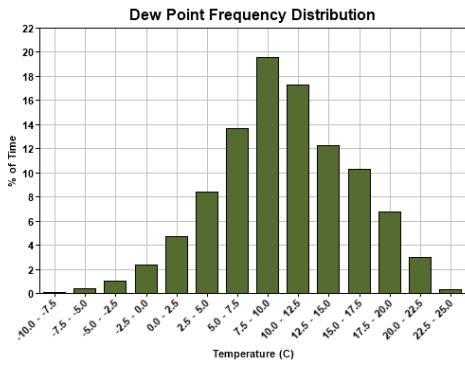


Figure 92: P1-Dew Point Frequency Distribution

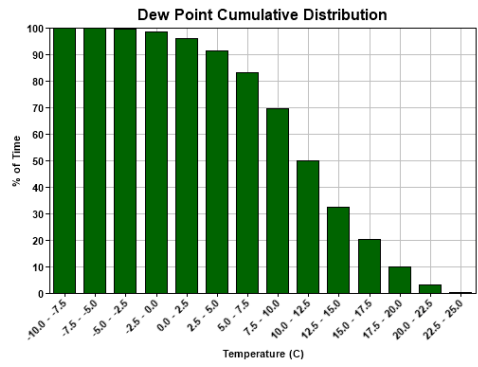


Figure 93: P1-Dew Point Cumulative Distribution

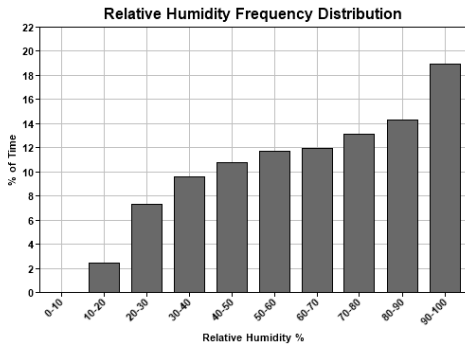


Figure 94: P1-Relative Humidity Frequency Distribution

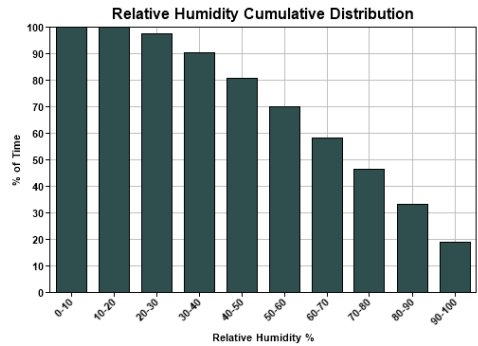


Figure 95: P1-Relative Humidity Cumulative Distribution

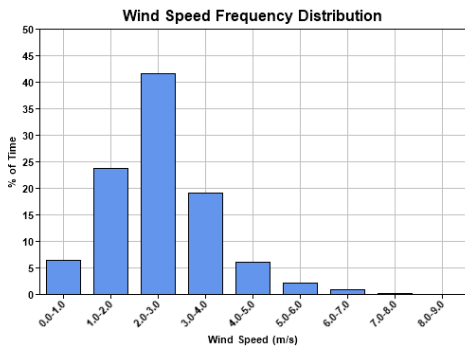


Figure 96: P1-Wind Speed Frequency Distribution

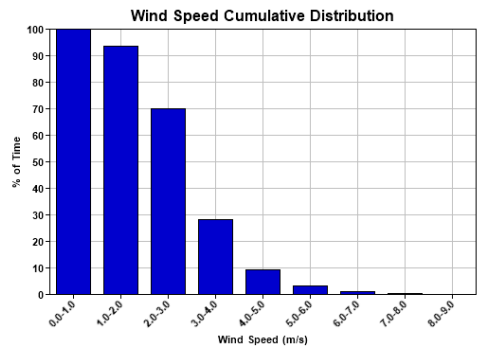


Figure 97: P1-Wind Speed Cumulative Distribution

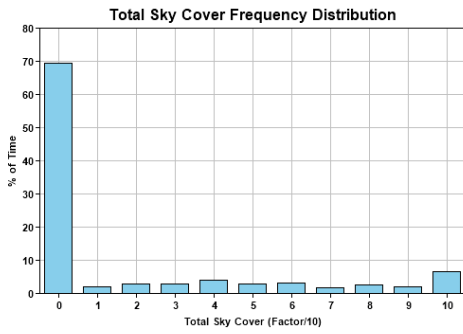


Figure 98: P1–Total Sky Cover Frequency Distribution

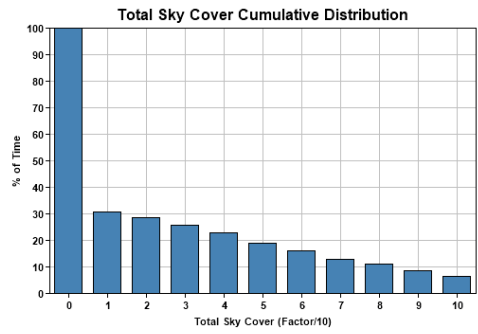


Figure 99: P1–Total Sky Cover Cumulative Distribution

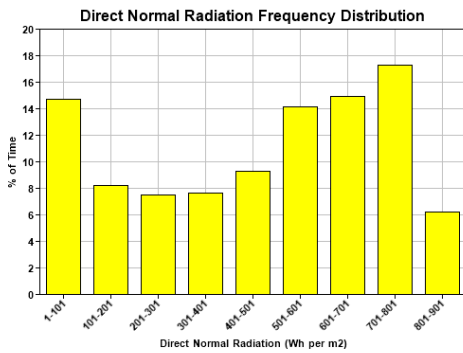


Figure 100: P1–Direct Normal Radiation Frequency Distribution

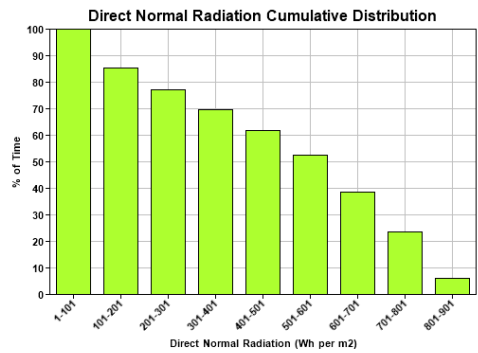


Figure 101: P1–Direct Normal Radiation Cumulative Distribution

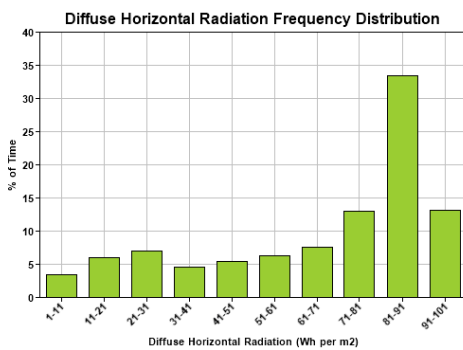


Figure 102: P1–Diffuse Horizontal Radiation Frequency Distribution

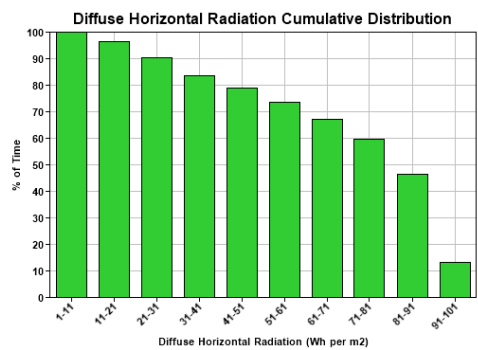


Figure 103: P1–Diffuse Horizontal Radiation Cumulative Distribution

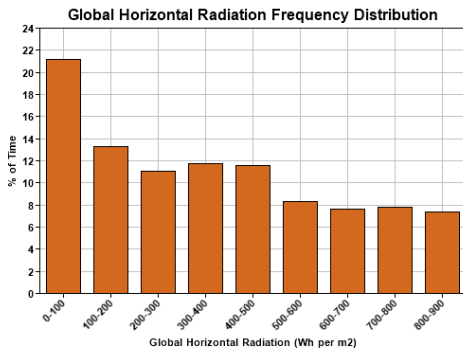


Figure 104: P1-Global Horizontal Radiation Frequency Distribution

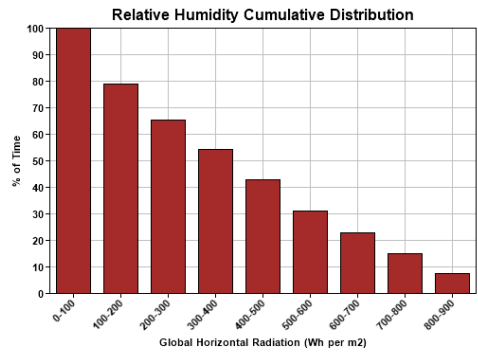


Figure 105: P1-Global Horizontal Radiation Cumulative Distribution

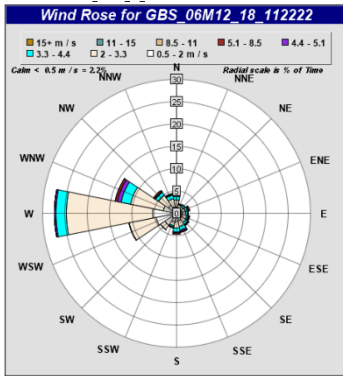


Figure 106: P1-Wind Rose

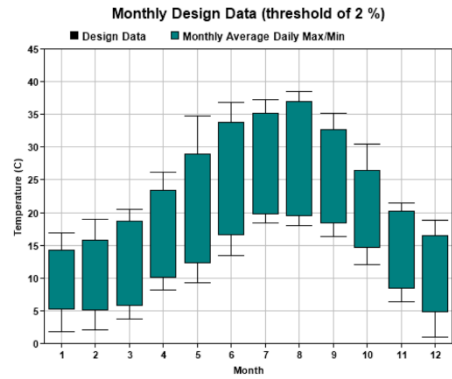


Figure 107: P1-Monthly Design Data

4.3.2 Category P2

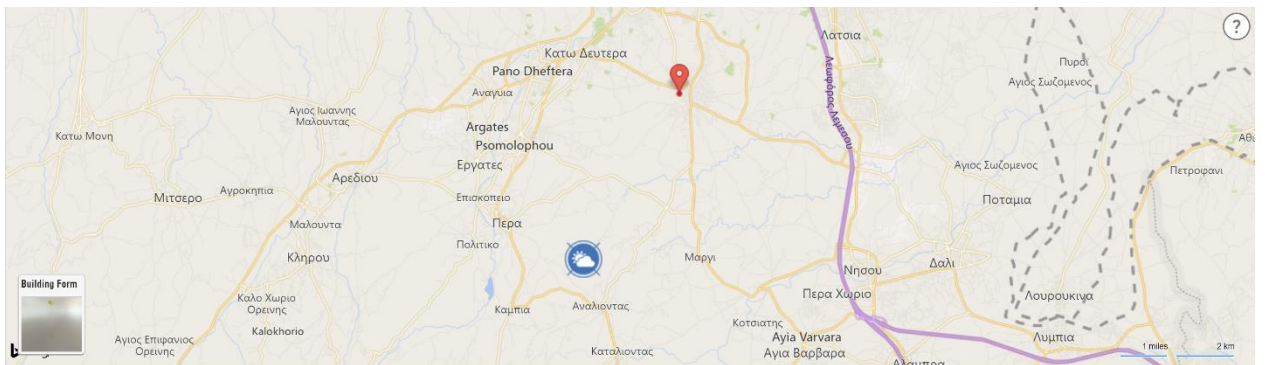


Figure 108: P2 - Location - Closest Meteorological Station

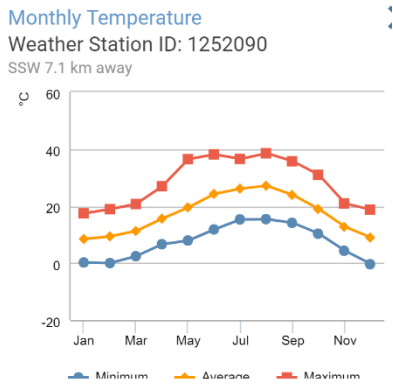


Figure 109: P₂ – Temperature Distribution (Insight 360)

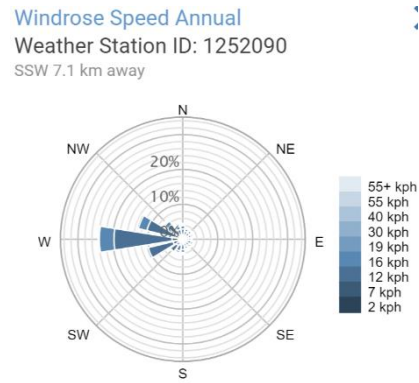


Figure 110: P₁ – Windrose Speed (Insight 360)


Weather Station: [GBS_06M12_18_111221](#) 
Distance to your project 4.4 mi (7.1 km)
Latitude = 35.0167 , Longitude = 33.2833

Figure 111: P₂ –Green Building Studio Weather Station

Table 14: P₂: Weather Summary

Cooling Degree Day		Heating Degree Day	
Threshold	Value	Threshold	Value
18.3 °C	983	18.3 °C	1261
21.1 °C	573	15.6 °C	743
23.9 °C	252	12.8 °C	344
26.7 °C	53	10 °C	111

Threshold	Annual Design Conditions			
	Cooling		Heating	
	Dry Bulb(°C)	MCWB(°C)	Dry Bulb(°C)	MCWB(°C)
0.1 %	37.4	21.1	-0.1	-1.2
0.2 %	37.1	21.2	0.2	-1.6
0.4 %	36.5	20.8	0.7	-1.1
0.5 %	36.3	20.6	1.0	-0.8
1 %	35.5	20.4	2.0	0.3
2 %	34.5	20.5	3.3	1.4
2.5 %	34.0	20.4	3.8	2.4
5 %	32.5	19.9	5.1	3.4

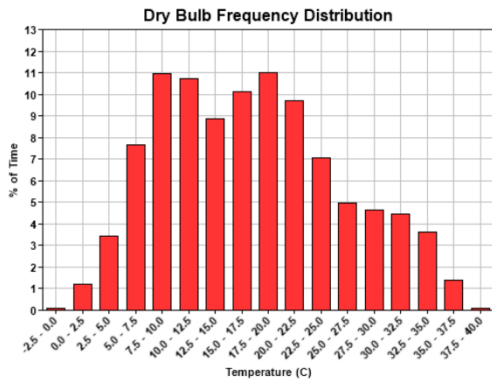


Figure 112: P₂-Dry Bulb Frequency Distribution

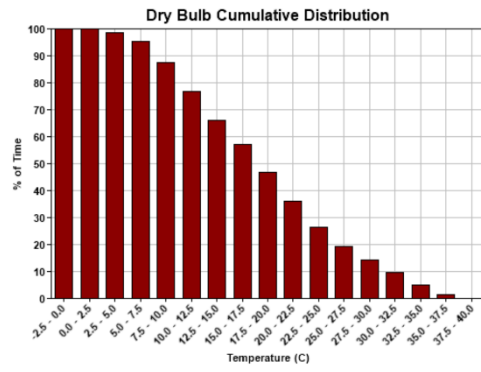


Figure 113: P₂-Dry Bulb Cumulative Distribution

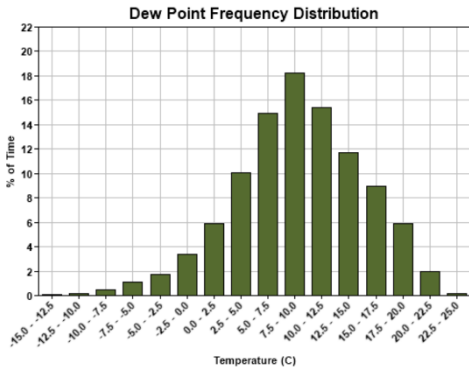


Figure 114: P₂-Dew Point Frequency Distribution

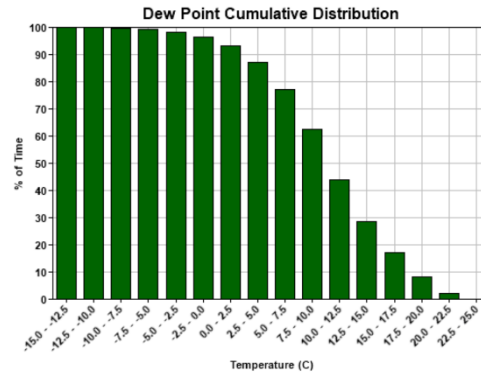


Figure 115: P₂-Dew Point Cumulative Distribution

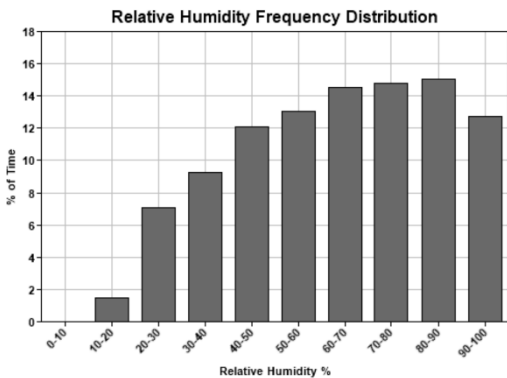


Figure 116: P₂-Relative Humidity Frequency Distribution

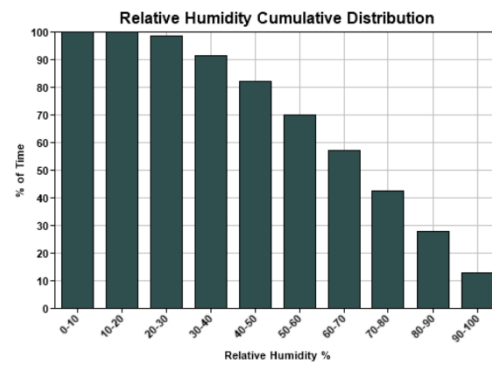


Figure 117: P₂-Relative Humidity Cumulative Distribution

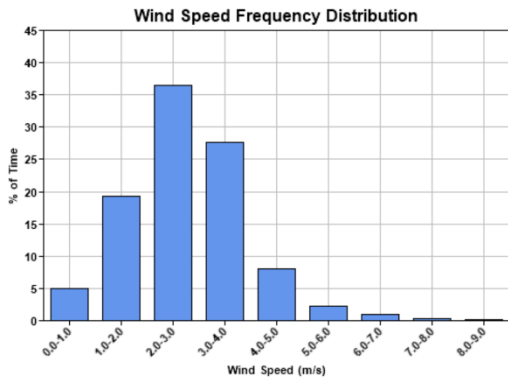


Figure 118: P₂-Wind Speed Frequency Distribution

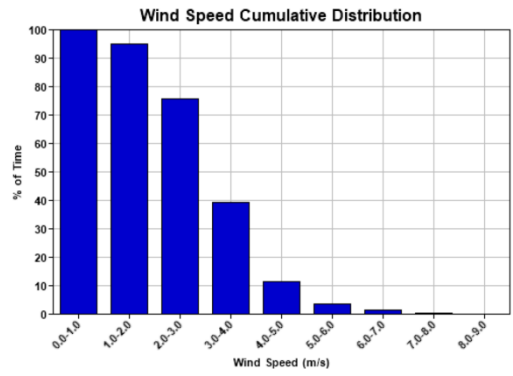


Figure 119: P₂-Wind Speed Cumulative Distribution

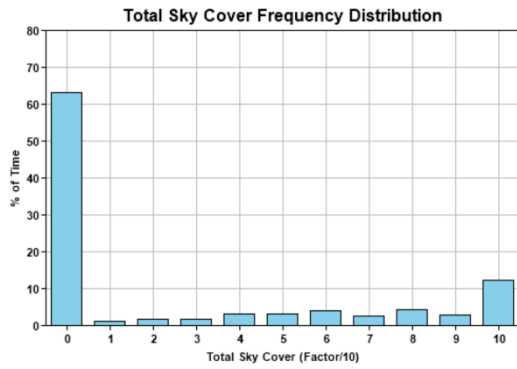


Figure 120: P₂-Total Sky Cover Frequency Distribution

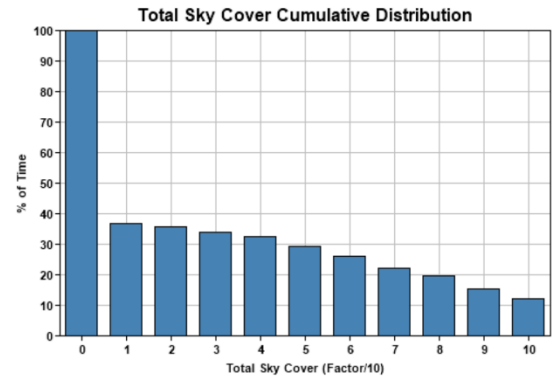


Figure 121: P₂-Total Sky Cover Cumulative Distribution

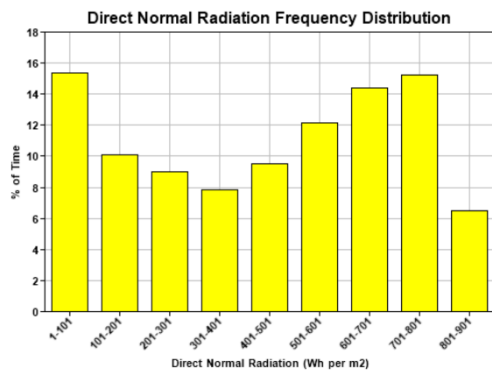


Figure 122: P₂-Direct Normal Radiation Frequency Distribution

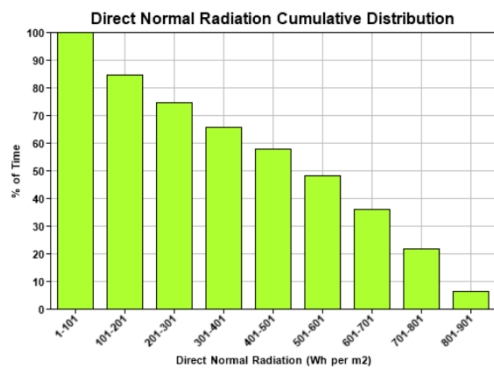


Figure 123: P₂-Direct Normal Radiation Cumulative Distribution

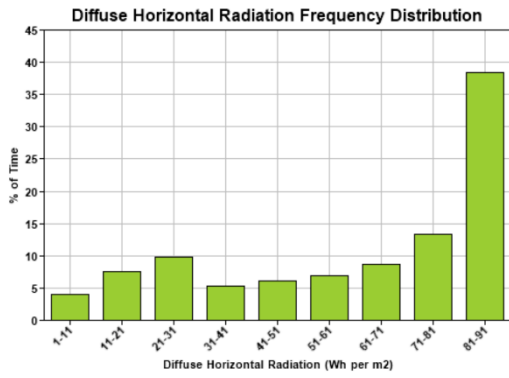


Figure 124: P₂-Diffuse Horizontal Radiation Frequency Distribution

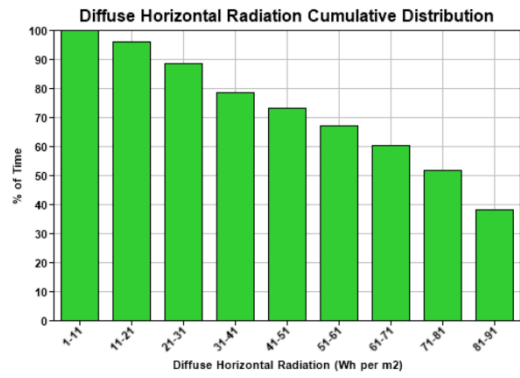


Figure 125: P₂-Diffuse Horizontal Radiation Cumulative Distribution

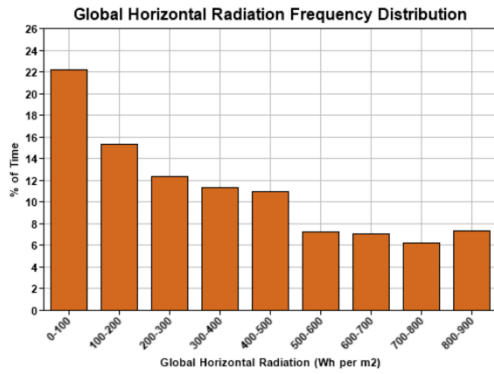


Figure 126: P₂-Global Horizontal Radiation Frequency Distribution

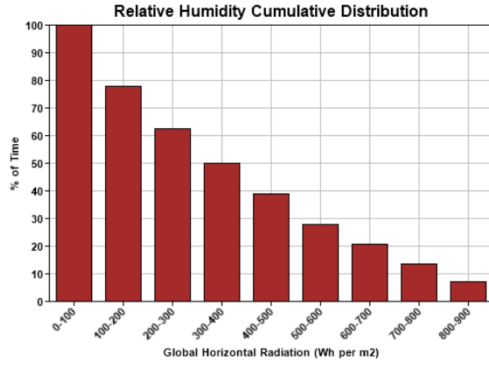


Figure 127: P₂-Global Horizontal Radiation Cumulative Distribution

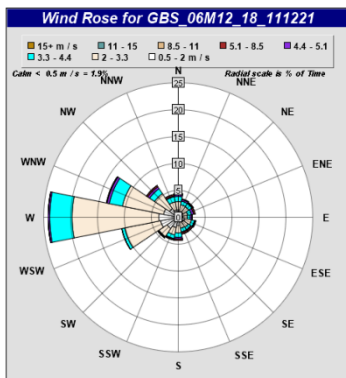


Figure 128: P₂-Wind Rose

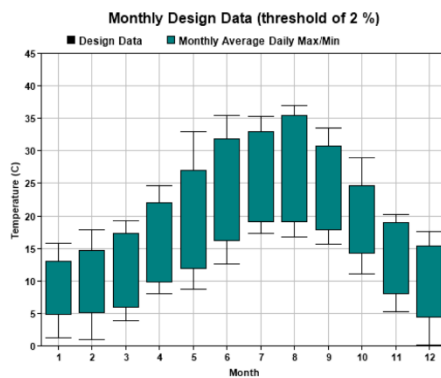


Figure 129: P₂-Monthly Design Data

4.3.3 Category P3

As observed by the Autodesk Green Building Studio website, the Weather Station used for the third model (Figure 130), was the same with the one used in the model of Period 1 (Figure 89) Thus, it can be assumed that the weather data of the region are the same.


Weather Station: [GBS_06M12_18_110222](#) 
 Distance to your project 4.5 mi (7.3 km)
 Latitude = 35.1167 , Longitude = 33.1500

Figure 130: P₃ –Green Building Studio Weather Station

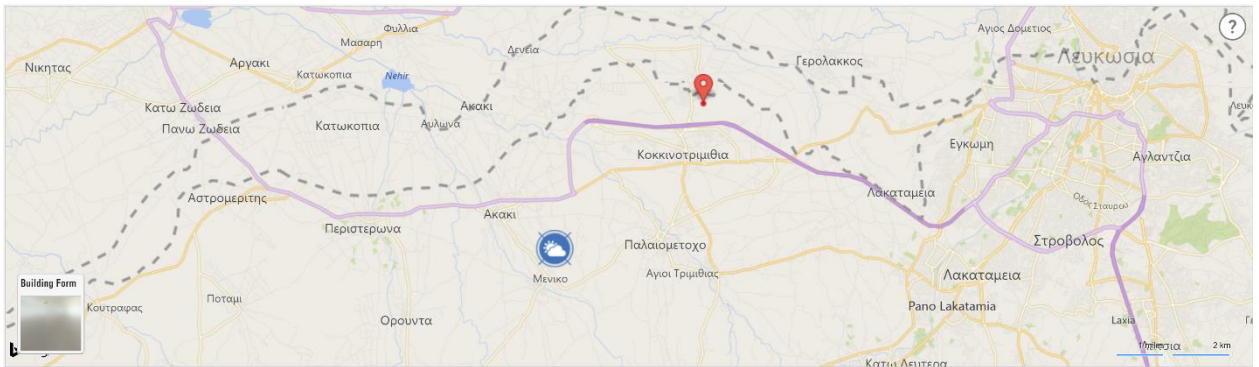


Figure 131: P₃ – Location – Closest Meteorological Station

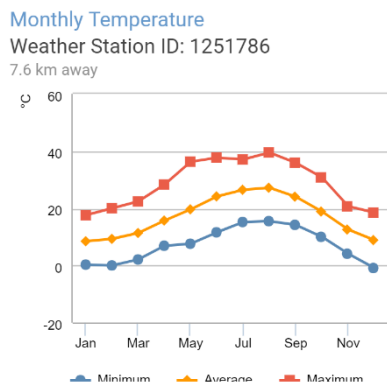


Figure 132: P₃ – Temperature Distribution (Insight 360)

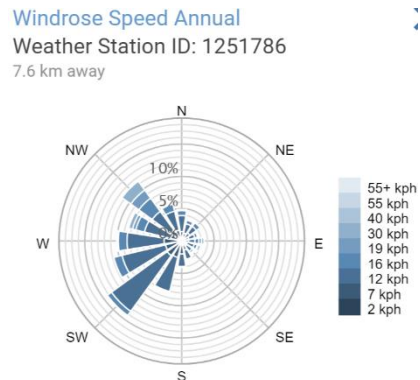


Figure 133: P₃ – Wind Rose Speed (Insight 360)

Table 15: P₃: Weather Summary

Cooling Degree Day		Heating Degree Day	
Threshold	Value	Threshold	Value
18.3 °C	1029	18.3 °C	1249
21.1 °C	613	15.6 °C	738
23.9 °C	286	12.8 °C	341
26.7 °C	67	10 °C	108

Annual Design Conditions				
Threshold	Cooling		Heating	
	Dry Bulb(°C)	MCWB(°C)	Dry Bulb(°C)	MCWB(°C)
0.1 %	38.7	20.8	-0.2	-1.3
0.2 %	37.5	20.5	0.1	-1.3
0.4 %	36.7	21.0	0.7	-1.4
0.5 %	36.6	20.8	1.1	-0.1
1 %	36.1	20.5	2.2	0.7
2 %	35.2	20.4	3.4	1.6
2.5 %	34.7	20.5	3.8	2.6
5 %	33.0	20.2	5.1	3.6

4.4. Energy Models

Ensuing the completion of the detailed models of each dwelling, the energy models were generated and checked to identify and assess any possible issues or mistakes. The analytical space and surface resolution was adjusted accordingly to get a model as much accurate and detailed as possible. The analytical surfaces and spaces are illustrated in the following figures and listed in the following tables.

4.4.1 Category P1: Energy Model, Spaces and Surfaces



Figure 134: P₁ - Energy Model

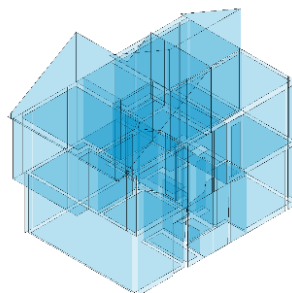


Figure 135: P₁ - Analytical Spaces

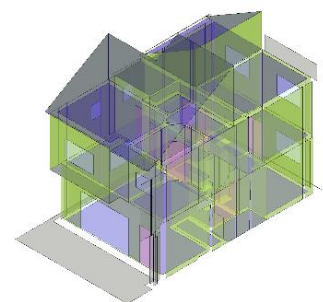


Figure 136: P₁ - Analytical Surfaces

Table 16: Category P₁ – Analytical Spaces

Analytical Spaces		
Room Name	Area	Volume
	0 m ²	35.83 m ³
	0 m ²	12.14 m ³
Bathroom 1 8	5 m ²	15.08 m ³
BathRoom 2 6	4 m ²	10.77 m ³
BedRoom 1 7	14 m ²	41.23 m ³
BedRoom 2 5	11 m ²	35.70 m ³
Bedroom 3 4	12 m ²	35.79 m ³
Kitchen 1	20 m ²	57.91 m ³
Staircase 2-2	39 m ²	127.97 m ³
Total	105 m ²	372.42 m ³

Table 17: Category P₁ – Analytical Surfaces

Analytical Surfaces		
Surface Type / Opening Type	Area	Count
Non-sliding Door	18 m ²	9
Operable Window	20 m ²	10
Exterior Wall	213 m ²	51
Interior Floor	48 m ²	11
Interior Wall	93 m ²	26
Raised Floor	3 m ²	1
Roof	105 m ²	11
Shade	28 m ²	9
Slab on Grade	54 m ²	3
Total	582 m ²	

4.4.2 Category P2: Energy Model, Spaces and Surfaces



Figure 137: P₂ – Energy Model

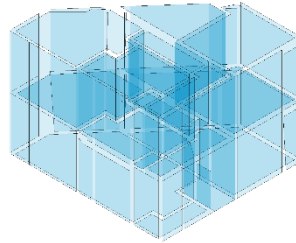


Figure 138: P₂ – Analytical Spaces

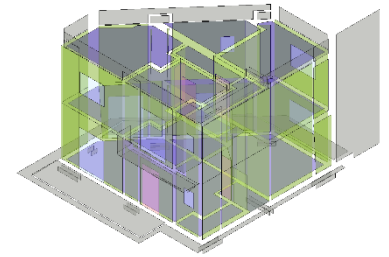


Figure 139: P₂ – Analytical Surfaces

Table 18: Category P₂ – Analytical Spaces

Analytical Spaces		
Room Name	Area	Volume
	1 m ²	0.89 m ³
Bathroom 7	5 m ²	12.54 m ³
Bedroom 14	10 m ²	30.99 m ³
Bedroom 26	7 m ²	22.71 m ³
Bedroom 35	12 m ²	33.14 m ³

Corridor 11	3 m ²	7.63 m ³
Kitchen 3	16 m ²	41.23 m ³
Staircase 10	30 m ²	76.76 m ³
Staircase (Floor) 12	0 m ²	10.11 m ³
Total	84 m ²	235.98 m ³

Table 19: Category P₂ – Analytical Surfaces

Analytical Surfaces		
Opening Type / Surface Type	Area	Count
Non-sliding Door	9 m ²	5
Operable Window	20 m ²	10
Exterior Wall	132 m ²	33

Interior Floor	38 m ²	7
Interior Wall	57 m ²	17
Roof	41 m ²	7
Shade	80 m ²	40
Slab on Grade	46 m ²	4
Total	423 m²	

4.4.3 Category P₃: Energy Model, Spaces and Surfaces

4.4.4



Figure 140: P₃ – Energy Model

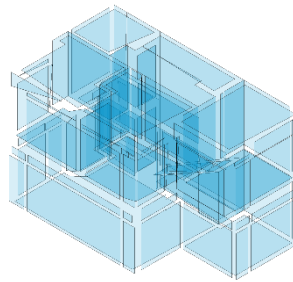


Figure 141: P₃-Analytical Spaces

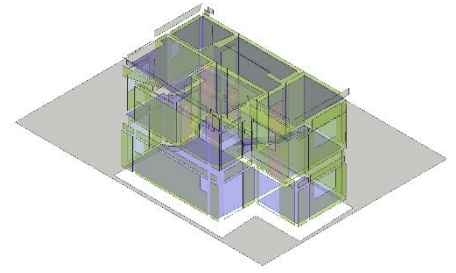


Figure 142: P₃-Analytical Surfaces

Table 20: Category P3 – Analytical Spaces

Analytical Spaces		
Room Name	Area	Volume
Bedroom 2 6	9 m ²	24.56 m ³
WC 2	2 m ²	5.28 m ³
Living Room 1	26 m ²	84.36 m ³
Kitchen 3	8 m ²	21.89 m ³
Storage 4	3 m ²	4.34 m ³
Bathroom 8	3 m ²	11.76 m ³
Bedroom 1 7	8 m ²	24.25 m ³
Bedroom 3 5	9 m ²	24.49 m ³
Corridor 10	4 m ²	10.34 m ³
Total	71 m²	211.27 m³

Table 21: Category P3 – Analytical Surfaces

Analytical Surfaces		
Surface Type / Opening Type	Area	Count
Non-sliding Door	12 m ²	8
Operable Window	19 m ²	14
Exterior Wall	130 m ²	58
Interior Floor	32 m ²	6
Interior Wall	55 m ²	23
Raised Floor	1 m ²	1
Roof	44 m ²	7
Shade	168 m ²	14
Slab on Grade	39 m ²	4
Total	499 m²	

4.5. Energy Settings

An effort was given in determining the optimum energy settings, to represent the real use and conditions of the residences. Initially, the default assumptions on energy settings for *single family* type dwellings and *residential operating schedule* were used, as set by the software, which are based on ASHRAE standards.

<https://knowledge.autodesk.com/support/revit-products/learn-explore/caas/CloudHelp/cloudhelp/2016/ENU/Revit-Analyze/files/GUID-552B1825-1323-4FBB-AE1C-BF447634E15E-htm.html>

Despite the fact that the default settings may not represent the installed technical systems and use of the buildings, they remained unchanged during all trials for simplicity and for comparison purposes.

The energy settings applied in all models represented a single family dwelling, with a default operating schedule, as listed in Table 22.

Table 22: Energy Settings applied in all models

Building Data	
Building Type	Single Family
Operating Schedule	Default
HVAC System	17 SEER/9.6 HSPF Split HP <5.5 ton
Outdoor Air per person	8 L/s
Air Changes per Hour	5

The default building type settings for single family building type used during the energy analysis are also shown in Figure 143, representing the software settings tab. Concerning the assumptions used during the analysis by the software, the building type data, operating schedule and HVAC system settings are shown in Figure 143, Figure 144, Figure 145, Figure 146 below:

Parameter	Value
Energy Analysis	
Area per Person	105.820 m ²
Sensible Heat Gain per person	73.27 W
Latent Heat Gain per person	58.61 W
Lighting Load Density	10.76 W/m ²
Power Load Density	10.76 W/m ²
Plenum Lighting Contribution	20.0000%
Occupancy Schedule	Home Occupancy - 24 Hours
Lighting Schedule	Residential Lighting - All Day
Power Schedule	Residential Lighting - All Day
Outdoor Air per Person	2.36 L/s
Outdoor Air per Area	0.30 L/(s·m ²)
Air Changes per Hour	0.000000
Outdoor Air Method	by People and by Area
Opening Time	01:00
Closing Time	00:00
Unoccupied Cooling Set Point	27.78 °C

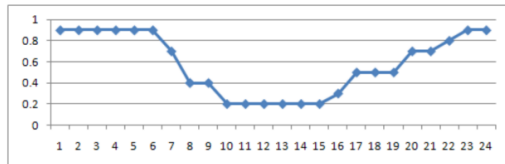
Figure 143: Building Type Settings

Single family

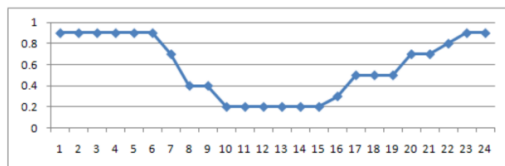
Parameter	Value
Occupancy Schedule	Residential
People/100 sq. M.	0.945
People Sensible Heat Gain (W/person)	70.0
People Latent Heat Gain (W/person)	45.0
Lighting Load Density (W/sq. M.)	4.8
Equipment Load Density (W/sq. M.)	4.6
Infiltration Flow (ACH)	0.5
Outside Air (ventilation air) Flow Per Person (liters per second)	NULL
Outside Air (ventilation air) Flow Per Area (cubic meters per hour per square meter)	1.1
Unoccupied Cooling Set Point (C)	29.4

Figure 144: Building Type Data

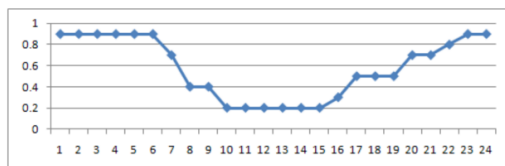
Occupancy-Residential



Residential schedule on weekdays



Residential schedule on Saturday



Residential schedule on Sunday

Figure 145: Building Operating Schedule

Residential 17 SEER/9.6 HSPF Split HP <5.5 ton

- 17.4 SEER/9.6 HSPF <5.5-ton split/package air source heat pump, intermittent fan mode
- Residential constant volume cycling fan
- 2.0 inch of water gauge (498 pascals) static pressure Constant Volume duct system
- Premium efficiency, on-demand tankless domestic hot water heater (0.85 Energy Factor)

Figure 146: HVAC System

4.6. Assessment of Energy Use Intensity

Subsequently, and given that the energy models of each dwellings were as accurate as possible, the data were uploaded to Insight 360 (<https://insight.autodesk.com/oneenergy>) and Green Building Studio (<https://gbs.autodesk.com/GBS/>), to generate the energy performance of the models, recognise any significant factors on improving the design and evaluate any possible trials and optimization.

4.6.1 Model P₁

According to the energy analysis conducted by using Insight, the most significant factors of the model existing design that could assist more in improving its energy performance and reduce its annual consumption, are mainly the HVAC system and the operating schedule. Following, the wall and roof construction holds a significant performance potential, and the Window to Wall Ratio (WWR) of Northern and Southern Walls. Other parameters like the building orientation, Window Glazing Types and Window Shading can offer to the performance increase of the model, but with a less impact.

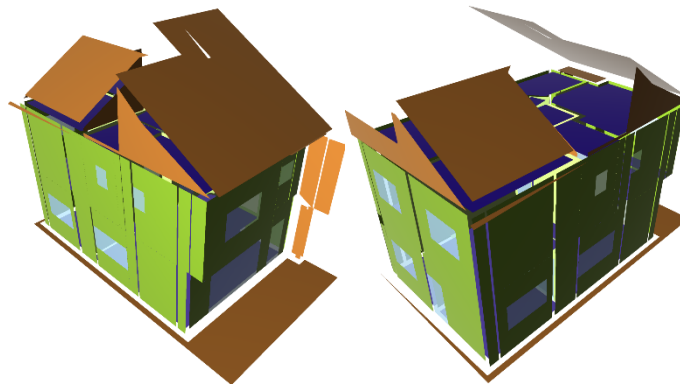


Figure 147:P₁ Insight Energy Models

4.6.2 Model P₂

Concerning the analysis of the second model, obviously one of the most significant design factors is again the HVAC system and the operating schedule. Following parameters

consist of the Window to Wall Ratio of the Western and Southern Walls, the roof and walls construction. Lowest impact values are observed on the Window to Wall Ratio of the Northern and Eastern Walls, the Building Orientation and the windows glazing type and shading.

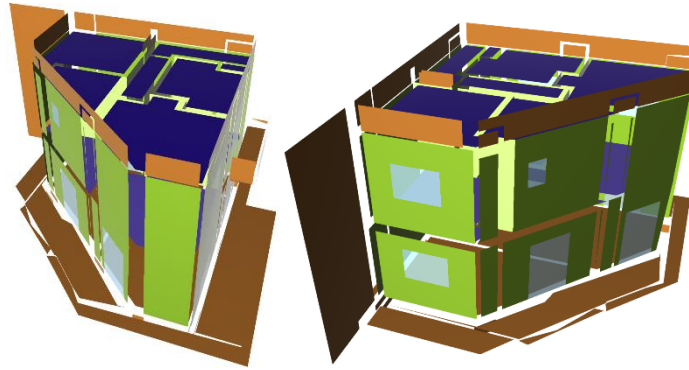


Figure 148:P₂ Insight Energy Models

4.6.3 Model P₃

Referring to the last model, the HVAC system and the operating system keep holding the most significant values on improvement potential. Since the construction of that dwelling included significant improvements on the thermal characteristics of the elements of the building shell, other factors such as plug load and lighting efficiency, seem to have higher values on design improvements. However, there is still a notable improvement depending on roof and wall construction and window glazing type. The lowest potential of alternative design options lies under window shading and building orientation options.

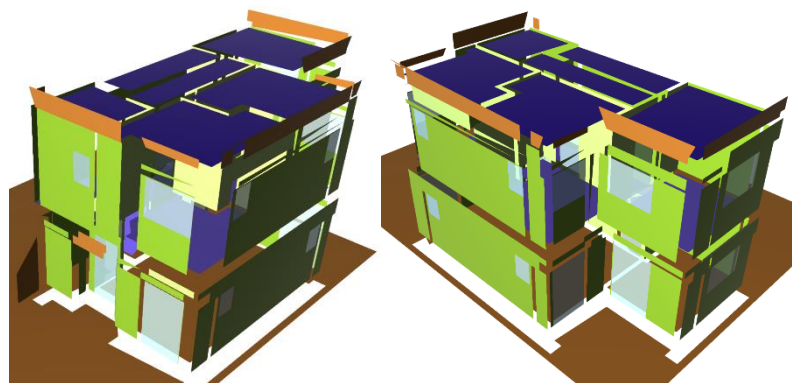


Figure 149:P₃ Insight Energy Models

4.7. Design Alternatives

Since the models represented simulations of existing models, it is obviously and technically impossible to apply modifications in all possible suggested design alternatives, such as building orientation. Even modification of Window to Wall Ratio would require a severe renovation and a highly increased cost.

Concerning modifications and improvements of HVAC system, plug load and lighting efficiency, and settings on operating system, and schedule are not taken into consideration, since they remain constant at all models and design alternatives.

Hence, the following enhancements, which represent the most common practises used in the country are applied to the models, run the simulation and evaluated:

Option 1: Existing Conditions

Option 2A: Addition of 50mm External Insulation (Extruded Polystyrene) on the building's envelope (roof, walls, columns, beams)

Option 2B: Replacement of Windows with double Low-e glazing windows

Option 3A: Addition of 100mm External Insulation (Extruded Polystyrene) on the building's envelope (roof, walls, columns, beams)

Option 3B: Replacement of Windows with triple Low-e glazing windows

Thus, after the application of the above improvements on the models and conducting their energy analysis, their energy performance was gradually improved. The results on the Energy Use Intensity of each alternative are shown below: (4.7.1 4.7.2 4.7.3)

4.7.1 Model P₁: Energy Use Intensity



Figure 150: P1 – Design Alternatives



Figure 151: P1 – Energy Use Intensity of Design Alternatives

4.7.2 Model P₂: Energy Use Intensity

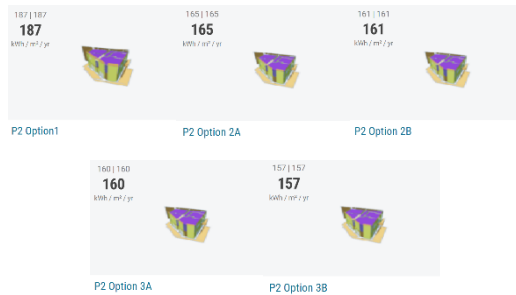


Figure 152: P1 – Design Alternatives



Figure 153: P1 – Design Alternatives

4.7.3 Model P₃: Energy Use Intensity

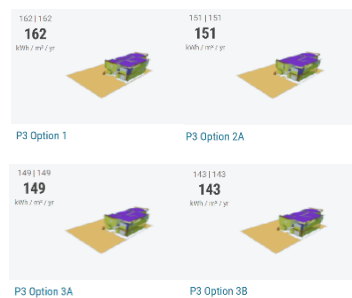


Figure 154: P1 – Design Alternatives

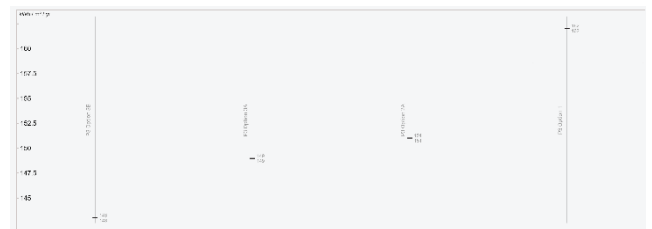


Figure 155: P1 – Design Alternatives

Table 23: Resulted Annual Cost and Annual Energy Use Intensity of each Design Option

Design Option	Annual Cost (€/m ²)	Annual EUI (kWh/m ²)
Model P₁		
1	46.50	262.57
2	41.88	237.56
2B	41.20	233.87
3A	41.12	233.49
3B	40.48	230.03
(Overall Reduction 32.54kWh/m ² or 13%)		
Model P₂		
1	32.49	187.38
2A	28.32	165.02
2B	27.56	160.90
3A	27.44	160.21
3B	26.85	157.06
(Overall Reduction 30.32kWh/m ² or 17%)		
Model P₃		
1	27.28	162.23
2A	25.24	150.90
2B	25.24	150.90
3A	24.91	148.90
3B	24.91	148.90
(Overall Reduction 13.33kWh/m ² or 8%)		

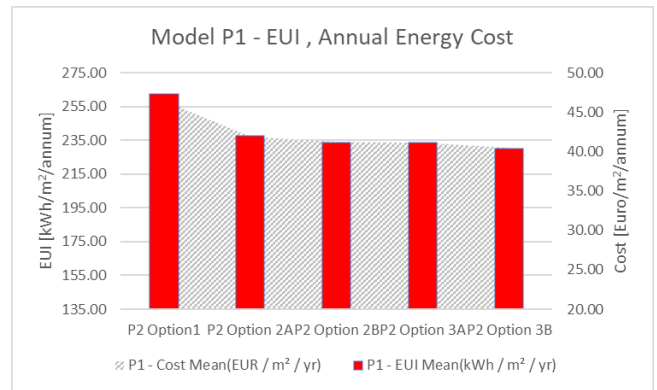


Figure 156: P₁- Annual Cost and Annual Energy Use Intensity of each Design Option

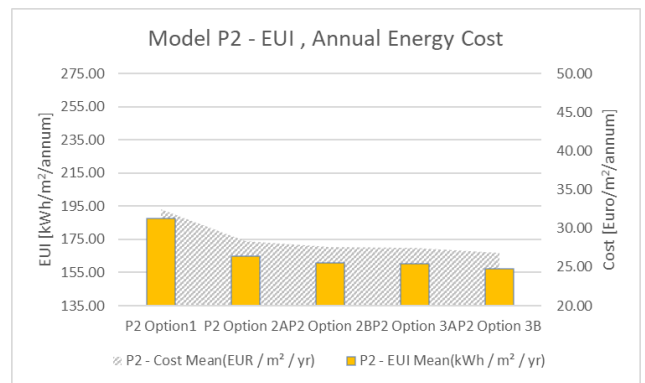


Figure 157: P₂- Annual Cost and Annual Energy Use Intensity of each Design Option

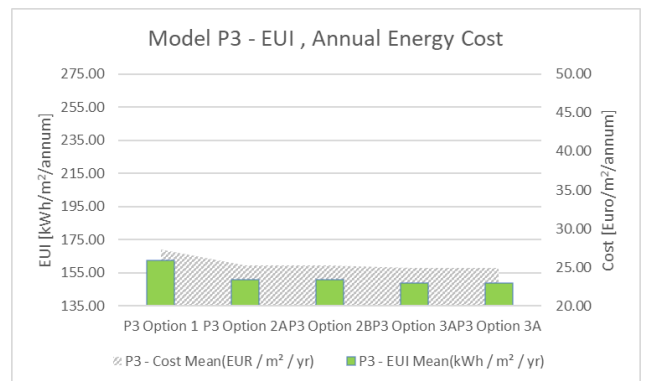


Figure 158: P₃- Annual Cost and Annual Energy Use Intensity of each Design Option

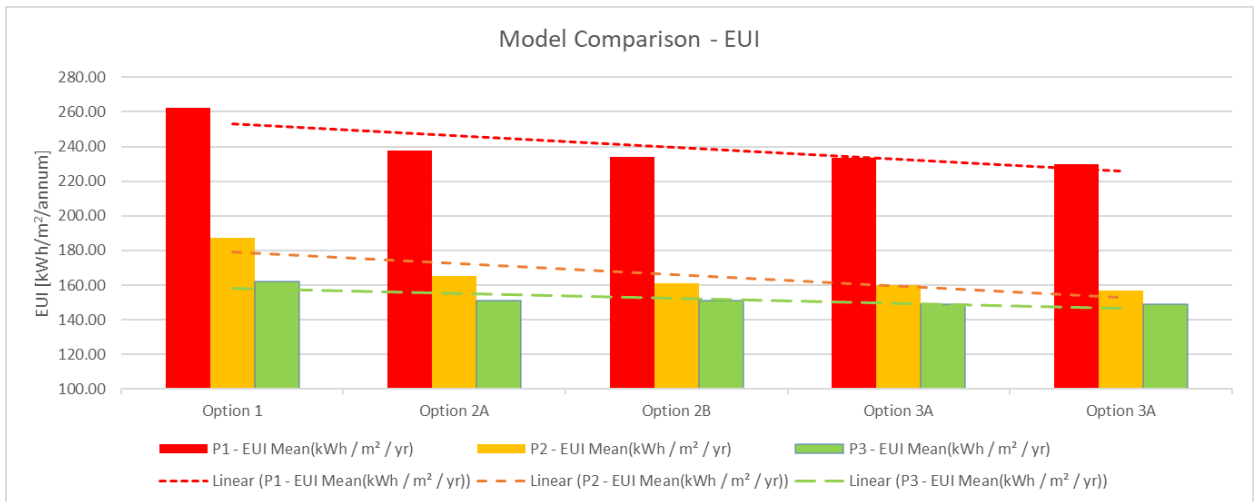


Figure 159: Comparison of Annual Energy Use Intensity of each Design Option for each model

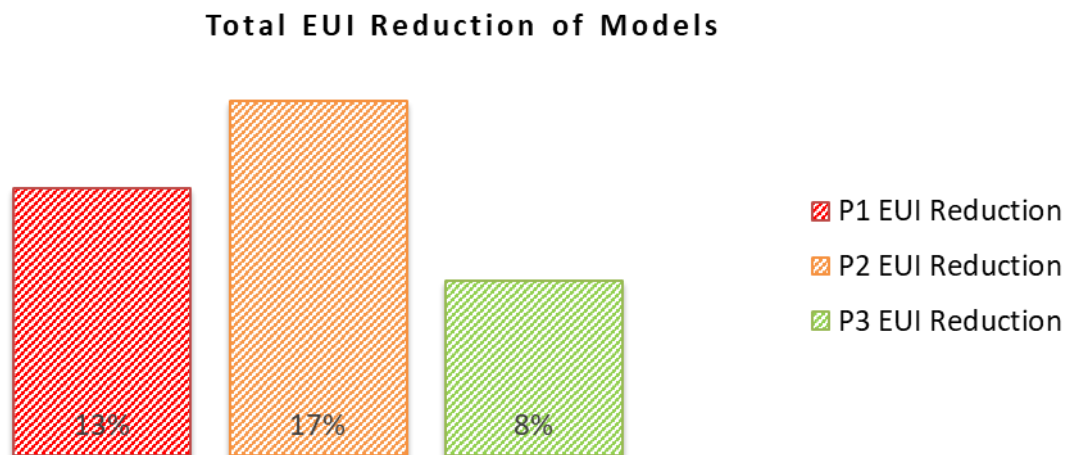


Figure 160: Comparison of Total Annual Energy Use Intensity Reduction of models

As illustrated on the above figure, a reduction of the Energy Use Intensity value of each model is observed, after applying the proposed enhancement measures. A higher declination in all models is noted at Design option 2A, which represents the insulation of the building's envelope. However, a more favourable improvement in the overall performance is noted at the first model, which was constructed by a totally non-insulated envelope.

Nonetheless, the total improvement had not been as much as expected. Thus, an additional investigation was conducted in the energy settings and assumptions applied by the software, to identify any issues on their interpretation.

4.8. Adjustment of Energy Settings

Since the results did not meet the initial expectations, an effort was given in comparing the results and the assumptions used with the ones used in the country for the procedure used for the purposes of issuing the Energy Performance Certificates. Even though the energy settings used by the software could not be edited by the version employed (Autodesk Revit 2017.2) this had been changed in the next version of the software. (Revit 2018.3)

Hence, the energy settings of the models were adjusted, in consistency to the assumptions used by the local authority at the isbemCy, according to the Article 5 of the directive 2010/31/EE (Ministry of Commerce, Industry and Tourism, 2013), and based on the relative standards (CYS EN ISO:13790 – replaced by CYS EN ISO 52016, CYS EN ISO 6946)

Thus, the spaces of each model were re-evaluated, and the following settings were applied:

Table 24: Parameters considered for the Adjustments on Energy Settings

Adjusted Settings based on local assumptions	
Building Systems	Table 3: Basic Reporting Table for Energy Performance Relevant Data - Existing Single Family Building A)
Building Type	Residential (Single Family House and Apartment Building)
Infiltration Rate	

	Quantity	Unit	Description
Air changes per hour	8	m ³ /h/m ²	Calculated for a Pressure Difference inside/outside of 50Pa

Building Systems

		Quantity	Units	Description
Ventilation System	Air changes per hour	Only Natural Ventilation	1/h	No Mechanical Ventilation
	Heat Recovery Efficiency	N/A	%	
Efficiencies of Heating System	Heat Generator Seasonal Efficiency	80	%	Ratio of Useful Heat output to Energy input over the Heating Season
Efficiencies of Cooling System	Cooling Seasonal Efficiency	250%	%	Ratio of Cooling Demand over Cooling Energy of the Generator

Efficiencies of DHW system	Heat Generator Seasonal Efficiency	80	%	Ratio of Useful Heat output to Energy input over the Heating Season
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Building Set Points and Schedules

		Quantity	Unit	Description
Temperature Set Point	Winter	18 (except lounge 21)	°C	Indoor Operative Temperature
	Summer	25 (except lounge 27)	°C	
Humidity Set point	Winter	N/A	%	Indoor Relative Humidity if applicable
	Summer	N/A	%	

Occupancy Schedules and Controls
(Annex II - Operation Schedule, set point Temperatures and Lighting for Reference buildings) - 1) Residential (Single Family House and Apartment Building)

Spaces - Activity	Occupancy Hours (Weekdays)	Occupancy Hours (Weekdays)	Cooling Set point (°C)	Heating Set point (°C)	Lighting (Lux)
Circulation Areas	7:00-09:00, 18:00-23:00	09:00-24:00	25	18	100
Lounge	18:00-22:00	10:00-24:00	25	21	150
Kitchen	06:00-09:00, 17:00-19:00	09:00-11:00, 13:00-14:00, 17:00-20:00	25	18	300
Dining Room	06:00-9:00, 18:00-20:00	09:00-11:00, 13:00-14:00, 18:00-21:00	25	18	150
Bathroom	06:00-9:00, 19:00-21:00	09:00-11:00, 19:00-21:00	27	18	150
Bedroom	21:00-09:00	21:00-11:00	25	18	100

Methodology for Assessing the Energy Performance of Buildings (MAEPB) Part VI , Reference Building (Infotrends Innovations & BRE, 2015)

Reference Number	Parameter	Value
(9)	Air penetration	10m ³ /(h.m ²) at 50 Pa.

(20) - Table E.5	Seasonal Efficiencies of HVAC System - Residential (Conditioned Spaces)	
	Cooling SSEER	3.2
	Heating SCoP	0.9
(23)	Total Efficiency of the DHW system	45%
		Fuel: Diesel
		Energy Demand: considered as the Energy required to increase the temperature of water from 10°C to 60°C
(27)	Lighting power	(Brightness/100) X 5.2W/m ² ανά 100 lux.
(30)	Lighting Control	Manual Switches

Methodology for Assessing the Energy Performance of Buildings (MAEPB) Part VII , Reference Building (Infotrends Innovations & BRE, 2015)

Default Values for the seasonal Efficiency of Heating and Cooling Systems with Heat pumps

New Buildings	Cooling SEER	3.6
	Heating SCoP	2.5
Existing Buildings	Cooling SEER	2.6
	Heating SCoP	1.9
Existing Buildings	Cooling SEER	3.2
	Heating SCoP	0.9

Table 25: Adjustments on Energy Settings

Adjusted Settings / Inputs to the Software for the Models	
Building Type	Single family (Edited)
Air changes per hour	8
Occupancy Schedule	Home Occupancy - 24 hours (Default)
Lighting Schedule	Residential Lighting – All Day (Default)

Power Schedule	Home Occupancy – 24 hours (Default)
Unoccupied Cooling Set Point	27°C
HVAC System	Unchanged - Residential 17 SEER/9.6 HSPF Split HP <5.5 ton

Heating and Cooling Loads Settings (General)

Building Service	Split System(s) with Natural Ventilation
-------------------------	--

Details / Spaces

Default	Heating Set Point	21.00 °C	Heating Air Temperature	32.22 °C
	Cooling Set Point	25.00 °C	Cooling Air Temperature	12.22 °C
Humidification Control	N/A			

Building Set Points and Schedules

Space Type (New-Edited Spaces) and Occupancy Schedules

Spaces - Activity	Occupancy Hours	Lighting load Density (W/m²)
Circulation Areas	7:00-09:00, 18:00-23:00	1.67
Lounge	18:00-22:00	2.5
Kitchen	06:00-09:00, 17:00-19:00	5.0
Dining Room	06:00-9:00, 18:00-20:00	2.5
Bathroom	06:00-9:00, 19:00-21:00	2.5
Bedroom	21:00-09:00	1.67

4.9. Final Energy Use Intensity

After the adjustment of the energy settings and the schedules, the models were updated, and run again using Insight 360. The updated results of Energy Use Intensity of each model and each design alternative using detailed elements option, were formed as indicated in Figure 167 and Figure 168:

4.9.1 Model P₁: Energy Use Intensity / Adjustments

The factor widget of the Insight 360 analysis for the existing conditions (Model P1 Option 1) are illustrated in the following figures (Figure 167), by which is shown the significance of parameters such as HVAC system, lighting and plug load efficiency, but also the construction of the walls and roof.

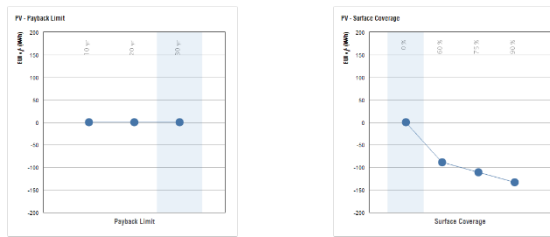


Figure 161 P₁: Insight 360 Factor Widgets



Figure 162: P₁ – Design Alternatives

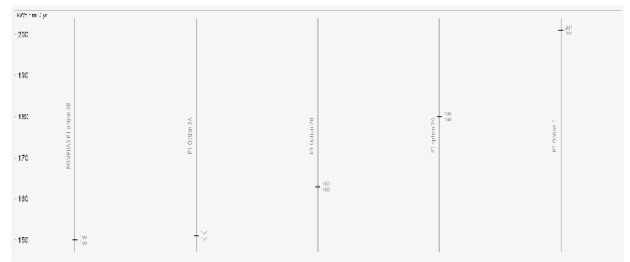


Figure 163: P₁ – Model Comparison - Energy Use Intensity of Design Alternatives

According to the above widgets (Figure 161), the most significant modifications are the HVAC system, the modification of the operating schedule, and plug load efficiency, having a reduction potential of 24kWh/m²/year, 45kWh/m²/year and 22kWh/m²/year. Another factor with a high potential seems to be the Windows to Wall ratio, which however in the case of the model under reference can reduce the Energy Use intensity only by 2.3kWh/m²/year, meaning that the WWR design of the model was adequate.

Concerning the building envelope, the roof construction type has a significant potential, equal to 30kWh/m²/year while the wall reaches about 2kWh/m²/year.

The optimum design option of the model occurs by adjusting the following elements and systems, according to a relative reduction percentage for each parameter (Table 26):

Table 26: P1-Insight 360 Optimum Design Alternatives

Optimum Option	Description	Initial EUI	201	Reduction potential of EUI (%)
		Type	Reduction potential of EUI (kWh/m2/year)	
1	HVAC Type	Ashrae Package Terminal Heat Pump	-23.91	-12%
2	Operating Schedule	12/05	-45.44	-23%
	Plug Load Efficiency	6.46W/m2	-21.55	-11%
	WWR-Western Walls	0%	-2.29	-1%
	Lighting Efficiency	BIM (as modeled)	0	0%
	WWR-Southern Walls	BIM (26%)	0	0%
	Roof Construction	R60	-29.97	-15%
	WWR-Northern Walls	0%	-1.98	-1%
	WWR-Eastern Walls	BIM(0%)	0	0%
	Wall Construction	14-inch ICF	-1.75	-1%
	Building Orientation	180 degrees	-0.16	0%
	Window Glass Types - West	Trp Lo-E	-0.61	0%
	Infiltration (ACH)	0.17 ACH	-0.37	0%
	Window Shades - West	2/3 Win Height	-1.41	-1%
	Window Glass Types - South	Trp LoE	-0.27	0%
	Daylight & Occupancy Controls	Daylight & Occupancy Control	-1.91	-1%
	Window Glass North	BIM - Trp LoE no change	0	0%
	Window Shades - South	1/2 Win Height	-0.29	0%

	Window Shades - North	No change - not required	0	0%
	Window Shades - East	No change - not required	0	0%
	Window Glass - East	No change - not required	0	0%

After adjusting and combining all options to their optimum type, the Energy Use Intensity of the model was reduced to the value of 96.8kWh/m²/year.

By setting a Payback limit of 30 years, to get a Zero or below Zero value of Energy Use Intensity, it is required to install PVs of 16-18.6% panel efficiency, under a 60% surface coverage, at the surfaces with the higher solar potential. (Figure 171)

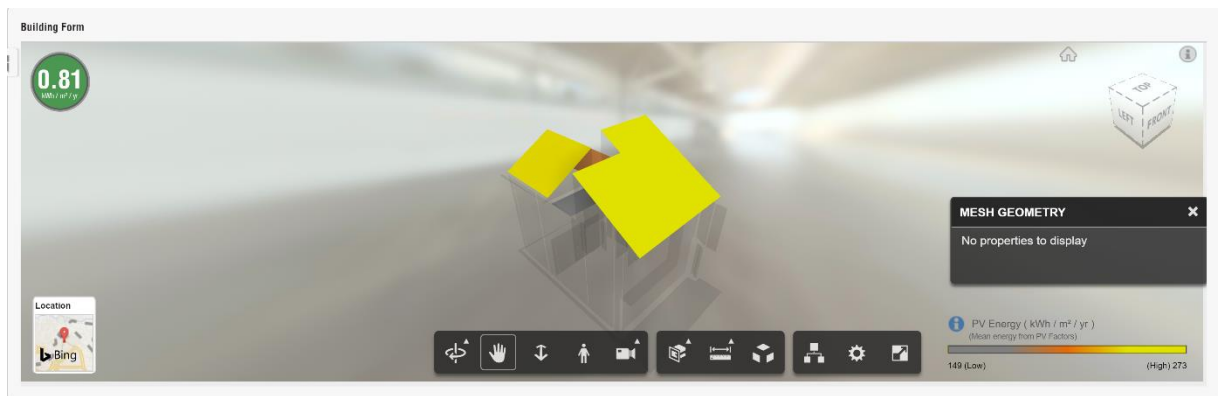


Figure 164: P1-PV Energy Potential

After the above modifications, the resulted Energy Use intensity of the model reaches almost the value of zero. (Figure 165, Figure 166)

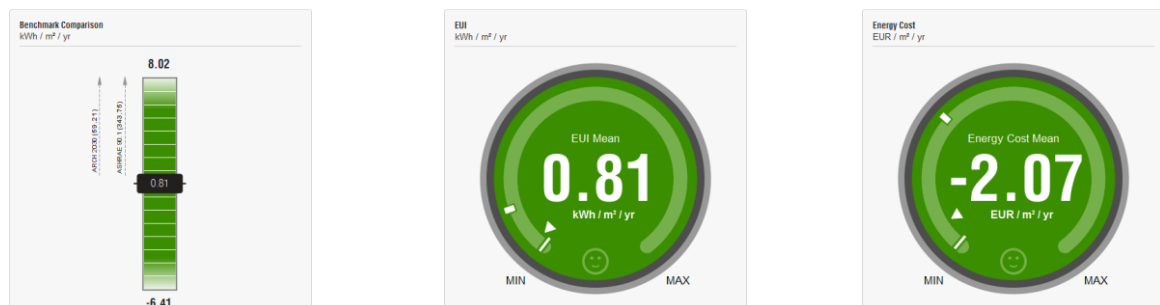


Figure 165: P1- Insight 360 Widgets- Optimum Design

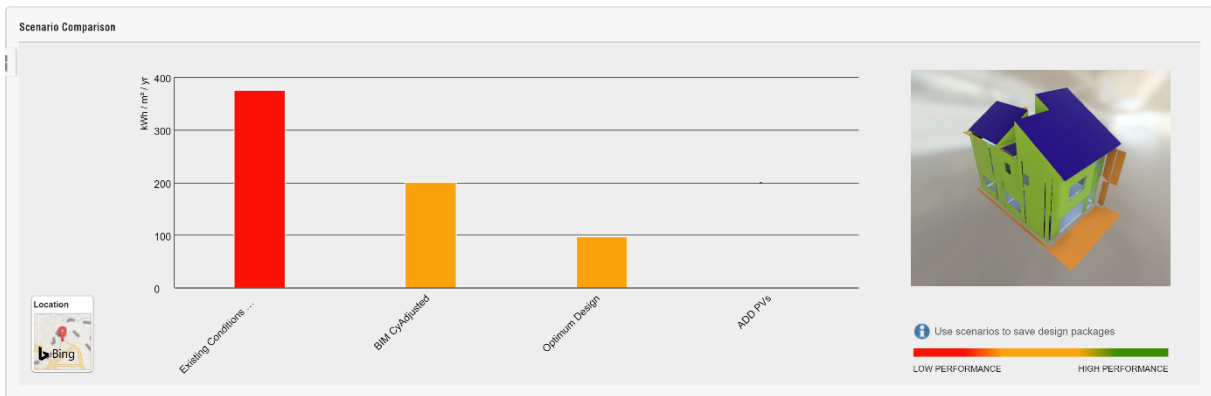


Figure 166: P1- Insight 360 Scenario Comparison



Figure 167: P1 – Design Alternatives – Detailed Elements



Figure 168: P1 – Model Comparison - Energy Use Intensity of Design Alternatives using Detailed Elements

4.9.2 Model P2: Energy Use Intensity / Adjustments

Concerning the second model, the factor widgets of the Insight 360 analysis for the existing conditions (Model P2 Option 1) are illustrated in the following figures (Figure 169), indicating again the significance of variable types of technical systems and construction of the roof and walls.

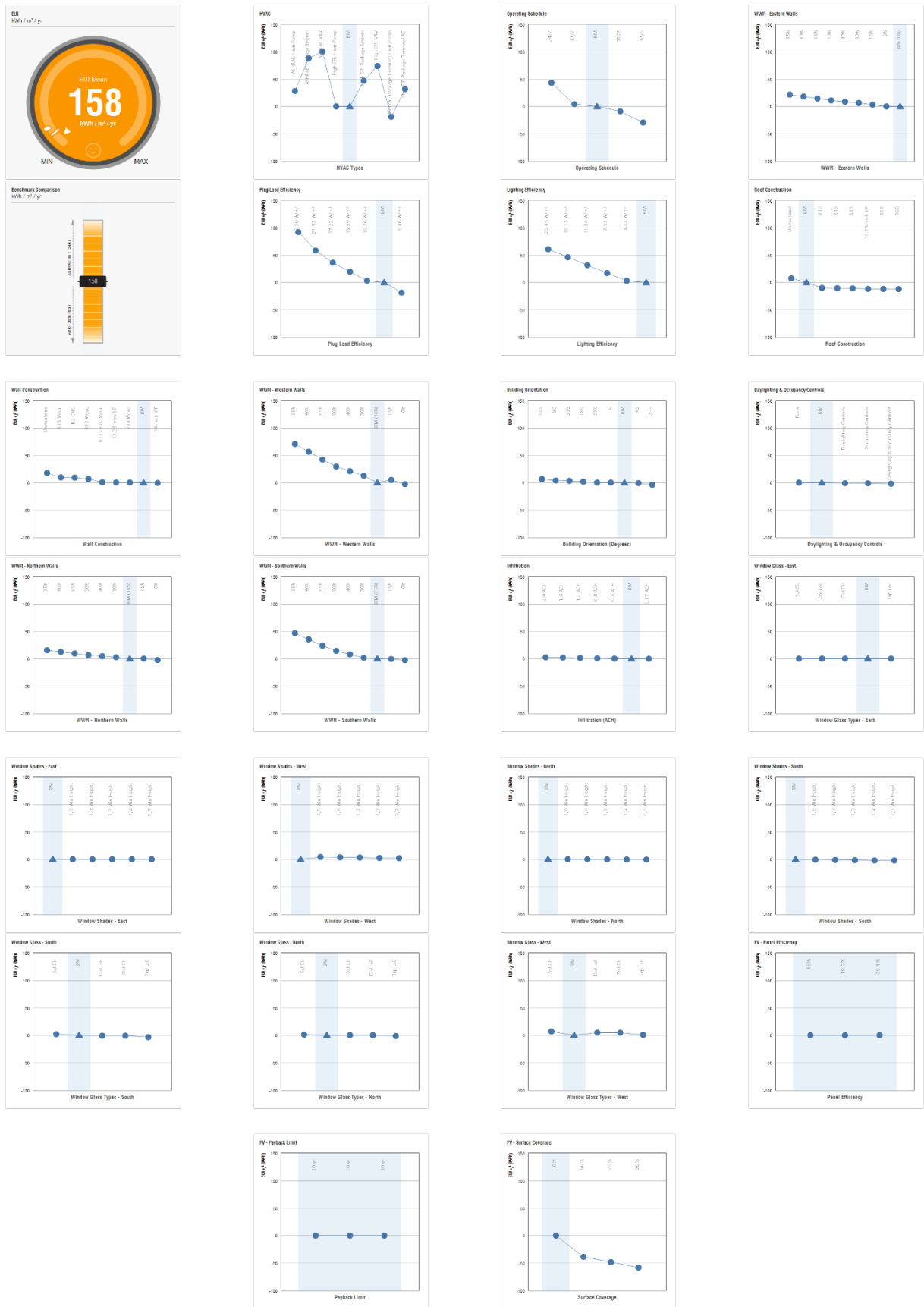


Figure 169 P2: Insight 360 Factor Widgets

Similarly, based on the Insight 360 widgets, the most significant modifications are the HVAC system, plug load efficiency, and the modification of the operating schedule, having a reduction potential of 19kWh/m²/year, 19kWh/m²/year and 30kWh/m²/year. Factors such as Window to Wall ratio and shading seem to be in almost the best possible design option, indicating that the design of the model was adequate.

Concerning the building envelope, the roof construction type has a significant potential, equal to 12.30kWh/m²/year while the wall reaches about 1kWh/m²/year.

The optimum design option of the model occurs by adjusting the following elements and systems, according to a relative reduction percentage for each parameter (Table 27):

Table 27: P₂-Insight 360 Optimum Design Alternatives

Optimum Option	Description	Initial EUI		
		Type	158	Reduction of EUI (kWh/m ² /year)
1	HVAC Type	Ashrae Package Terminal Heat Pump	-18.99	-9%
2	Operating Schedule	12/05	-29.41	-15%
	Plug Load Efficiency	6.46W/m ²	-18.77	-9%
	WWR-Western Walls	0%	-2.74	-1%
	Lighting Efficiency	BIM (as modeled)	0	0%
	WWR-Southern Walls	BIM (25%)	0	0%
	Roof Construction	R60	-12.3	-6%
	WWR-Northern Walls	0%	2.59	1%
	WWR-Eastern Walls	BIM(0%)	0	0%
	Wall Construction	14-inch ICF	-0.63	0%
	Building Orientation	225 degrees	-3.91	-2%

	Window Glass Types - West	Trp Lo-E	0	0%
	Infiltration (ACH)	0.17 ACH	-0.35	0%
	Window Shades - West	BIM	0	0%
	Window Glass Types - South	Trp LoE	-3.28	-2%
	Daylight & Occupancy Controls	Daylight & Occupancy Control	-2.03	-1%
	Window Glass North	BIM - Trp LoE no change	0	0%
	Window Shades - South	1/4 Win Height	-3.38	-2%
	Window Shades - North	No change - not required	0	0%
	Window Shades - East	No change - not required	0	0%
	Window Glass - East	No change - not required	0	0%

By adjusting and combining all options to their optimum type, the Energy Use Intensity of the model was reduced to the value of 85.7kWh/m²/year.

Thus, by keeping the Payback limit to the period of 30 years, the result of a Zero or below Zero value of Energy Use Intensity was obtained by assuming the installation of PVs of 18.6-20.4% panel efficiency, under a 60% surface coverage, at the surfaces with the higher solar potential.

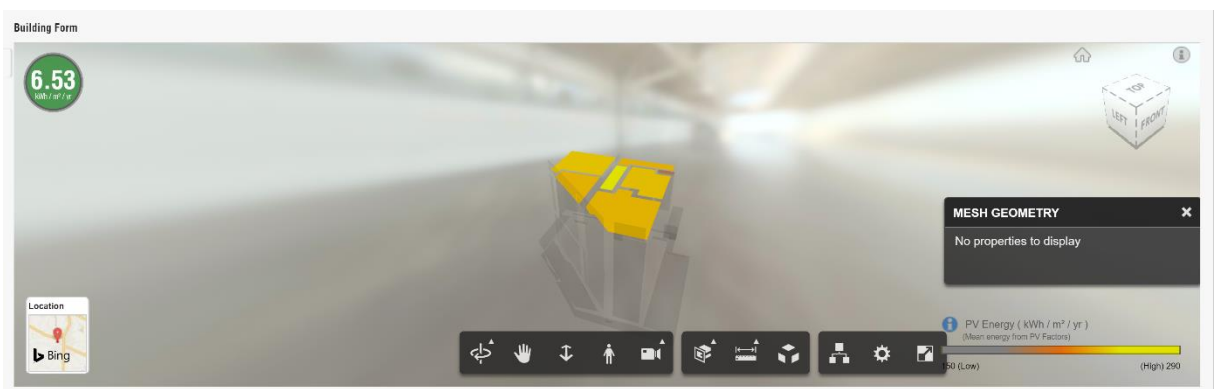


Figure 170: P₂-PV Energy Potential

The resulted Energy Use intensity of the model after all modification to their optimum type reaches almost the value of zero(Figure 171, Figure 172). As can be observed by the above figure, the second model has a higher solar potential than the first one.



Figure 171: P2- Insight 360 Widgets- Optimum Design

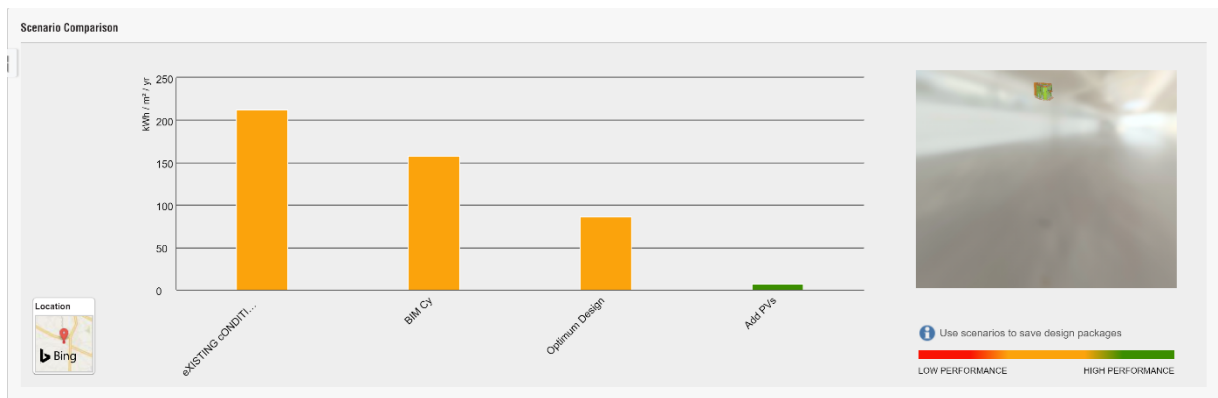


Figure 172: P2- Insight 360 Scenario Comparison

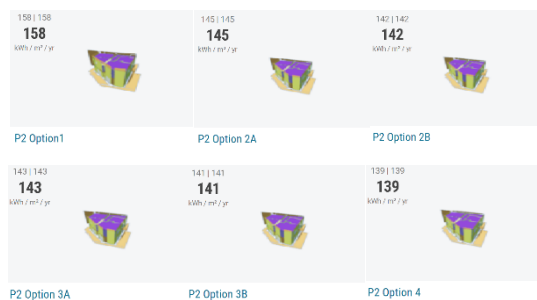
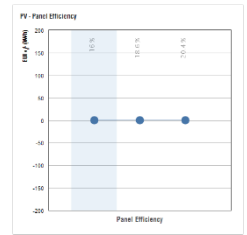
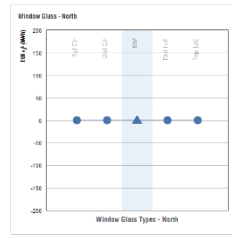
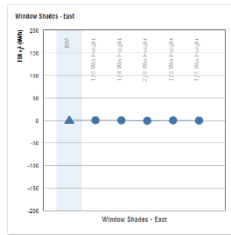
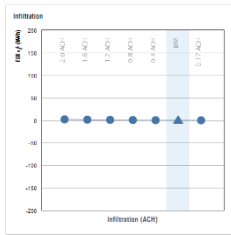
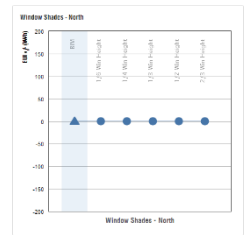
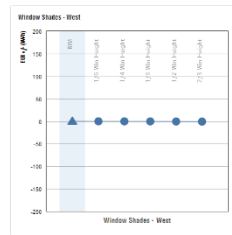
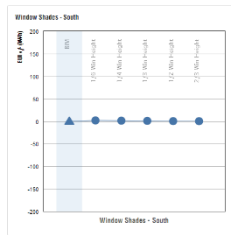
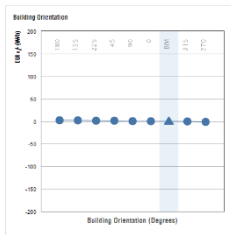
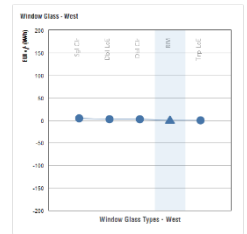
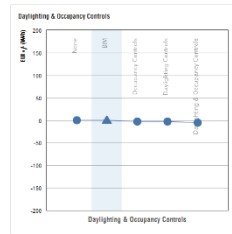
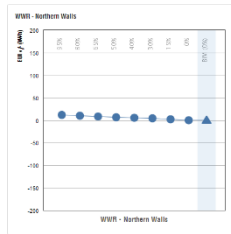
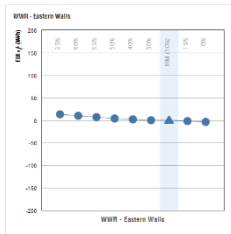
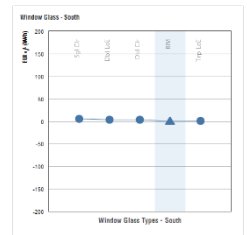
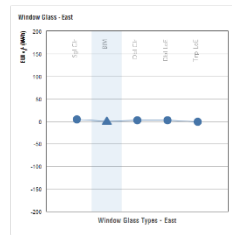
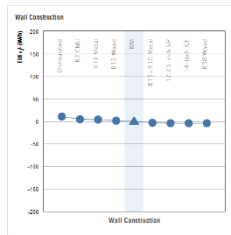
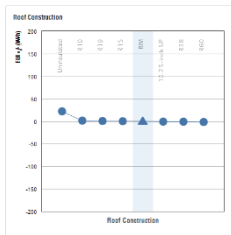
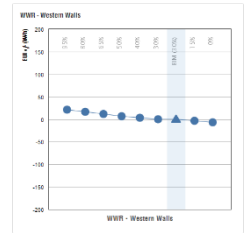
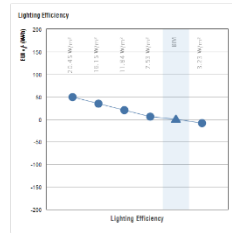
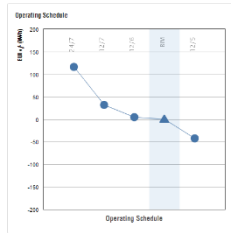
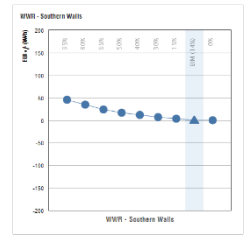
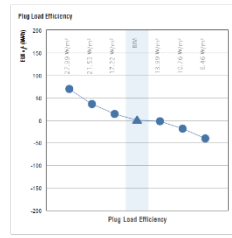
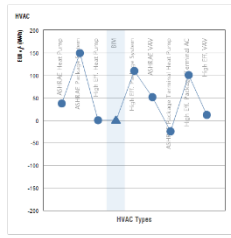
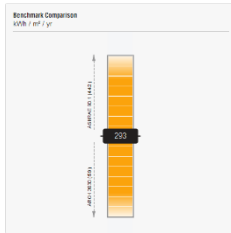
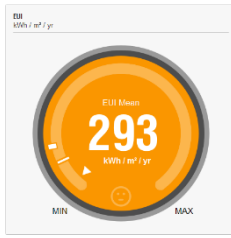


Figure 173: P2 – Design Alternatives (Using Detailed Elements)



Figure 174: P2 – Model Comparison - Energy Use Intensity of Design Alternatives (Using Detailed Elements)

4.9.3 Model P3: Energy Use Intensity



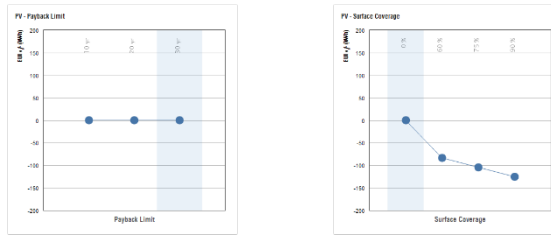


Figure 175 P3: Insight 360 Factor Widgets

According to the indications by Insight 360 (Figure 175) and similarly to the previous cases, the modifications with the highest potential are the HVAC system, plug load and lighting efficiency, and the modification of the operating schedule, resulting in reduction equal to 25kWh/m²/year, 40kWh/m²/year, 9kWh/m²/year and 42kWh/m²/year respectively. Window to Wall ratio of Western Walls seem to require more attention, since a reduction of WWR on these walls can reduce EUI from 4-69kWh/m²/year.

The building envelope of this model seems to have a better initial design and thermal characteristics, bearing in mind that the roof construction type has a reduction potential of just 1.65kWh/m²/year, while from the other side the wall construction type potential can offer up to 4.5kWh/m²/year.

The optimum design option of the model occurs by adjusting the following elements and systems, according to a relative reduction percentage for each parameter (Table 28):

Table 28: P3-Insight 360 Optimum Design Alternatives

Optimum Option	Description	Initial EUI 293		
		Type	Reduction of EUI (kWh/m ² /year)	Reduction of EUI (%)
1	HVAC Type	Ashrae Package Terminal Heat Pump	-24.72	-8%
2	Operating Schedule	12/05	-42.4	-14%
	Plug Load Efficiency	6.46W/m ²	-40.34	-14%
	WWR-Western Walls	0%	-6.79	-2%
	Lighting Efficiency	3.23/m ²	-8.6	-3%

	WWR-Southern Walls	BIM (14%)	0	0%
	Roof Construction	R60	-1.65	-1%
	WWR-Northern Walls	(BIM)0%	0	0%
	WWR-Eastern Walls	0%	-3.74	-1%
	Wall Construction	R38 Wood	-4.35	-1%
	Building Orientation	270 degrees	-1.43	0%
	Window Glass Types - West	Trp Lo-E	-0.22	0%
	Infiltration (ACH)	0.17 ACH	-0.22	0%
	Window Shades - West	2/3 Win Height	-0.76	0%
	Window Glass Types - South	BIM (DbllLoE)	0	0%
	Daylight & Occupancy Controls	Daylight & Occupancy Control	-5.37	-2%
	Window Glass North	BIM - Dbl LoE	0	0%
	Window Shades - South	BIM	0	0%
	Window Shades - North	BIM	0	0%
	Window Shades - East	2/3 Win Height	-1.16	0%
	Window Glass - East	TrpLoE	-1.21	0%

Following the adjustment and combination of all optimum type design options, the Energy Use Intensity of the model became 175kWh/m²/year, higher than the previous ones though.

Hence, by keeping the Payback limit to the period of 30 years, it was only possible to obtain a nearly Zero value of Energy Use Intensity (15kWh/m²/year) by assuming the installation of 20.4% panel efficiency PVs, under a 90% surface coverage, at the surfaces with the higher solar potential.



Figure 176: P3-PV Energy Potential

The resulted Energy Use Intensity of the model after all above modification to their optimum type reaches the value of 15kWh/m²/year, even though it seems to have a higher solar potential than the previous models, as illustrated in the above figure.

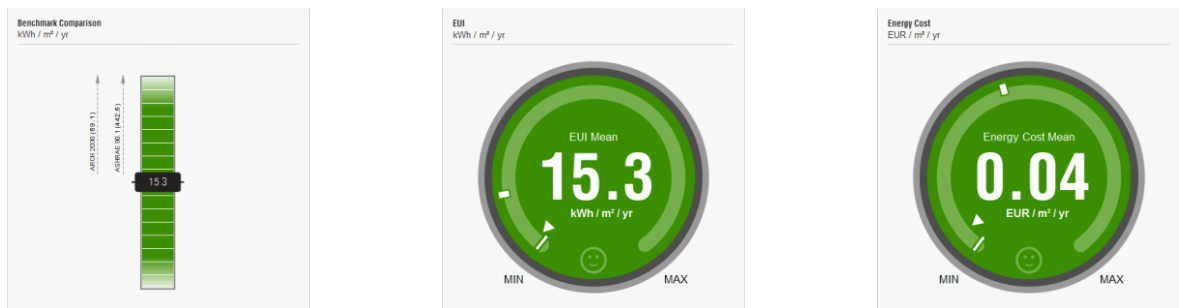


Figure 177: P3- Insight 360 Widgets- Optimum Design

Trial 1

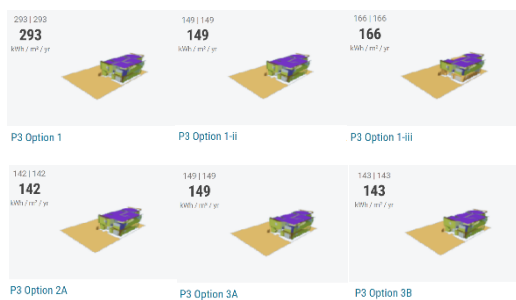


Figure 178: P3A – Design Alternatives

Trial 2

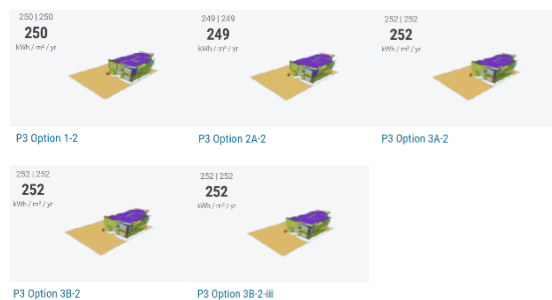


Figure 179: P3B – Design Alternatives

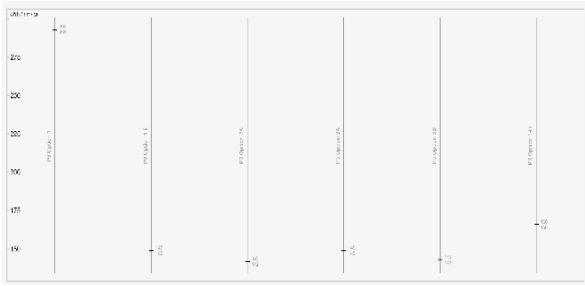


Figure 180: P_{3A} – Model Comparison - Energy Use Intensity of Design Alternatives

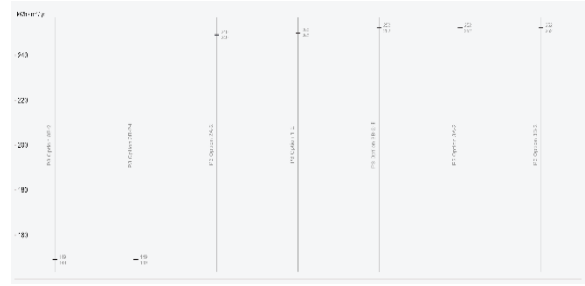


Figure 181: P_{3B} – Model Comparison - Energy Use Intensity of Design Alternatives

Since the results extracted for the models of the third period did not look, additional runs and trials were applied in an effort of identifying possible issues. First trials were applied with the same settings, while the last was applied by changing the export option from “spaces” to “rooms”.

However, even then, no significant modification was noticed in the analysis results, as shown in Figure 184 below. Thus, the results of the first run (with adjusted settings) were taken into consideration.

Model Name	EUI Mean (kWh / m² / yr)	Cost Mean (EUR / m² / yr)
P3 Option 1-2	250	43.4
P3 Option 2A-2	249	43.4
P3 Option 3A-2	252	43.8
P3 Option 3B-2	252	43.8

Figure 182: P_{3C} – EUI of Design Alternatives

Model Name	EUI Mean (kWh / m² / yr)	Cost Mean (EUR / m² / yr)
P3(rooms) Option 1	268	46.7
P3(rooms) Option 2A	266	46.4
P3(rooms) Option 3A	269	46.9
P3(rooms) Option 3B	269	46.9

Figure 183: P_{3D} – EUI of Design Alternatives

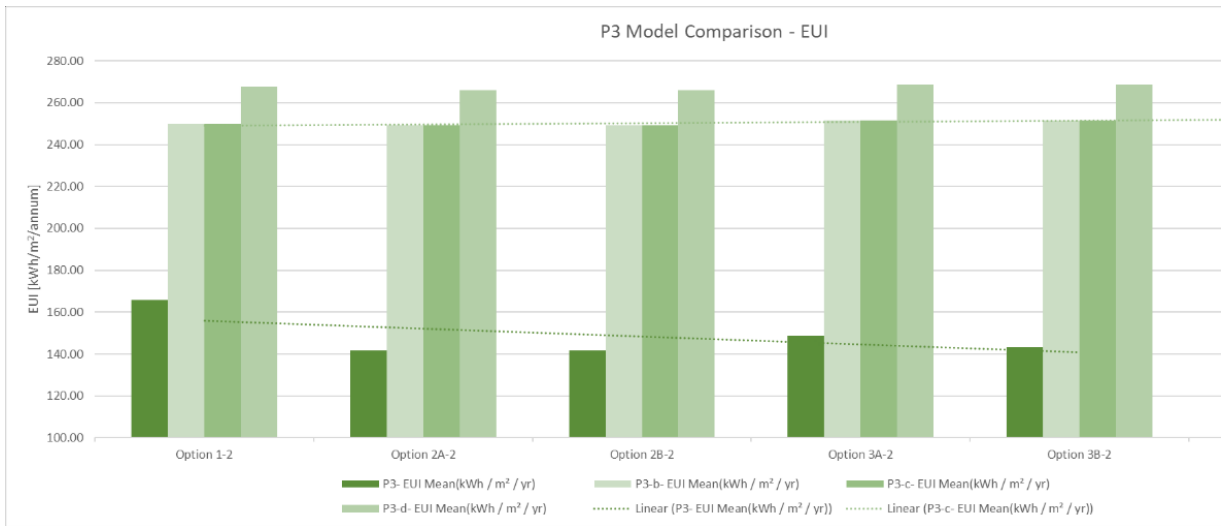


Figure 184: Comparison of EUI of variable trials of Design Options of P₃ models

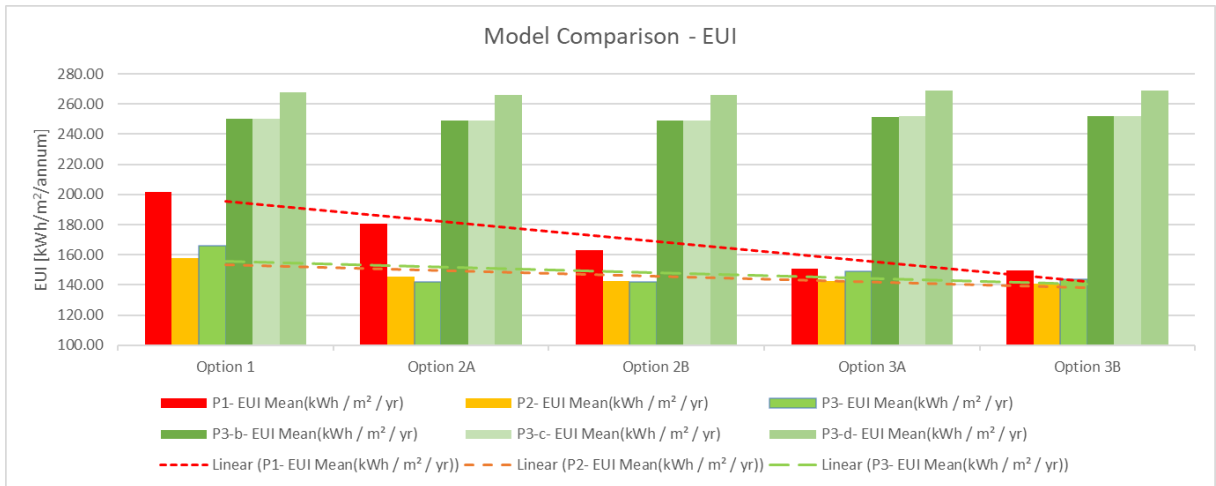


Figure 185: Comparison of EUI of variable design options of all models with adjusted settings

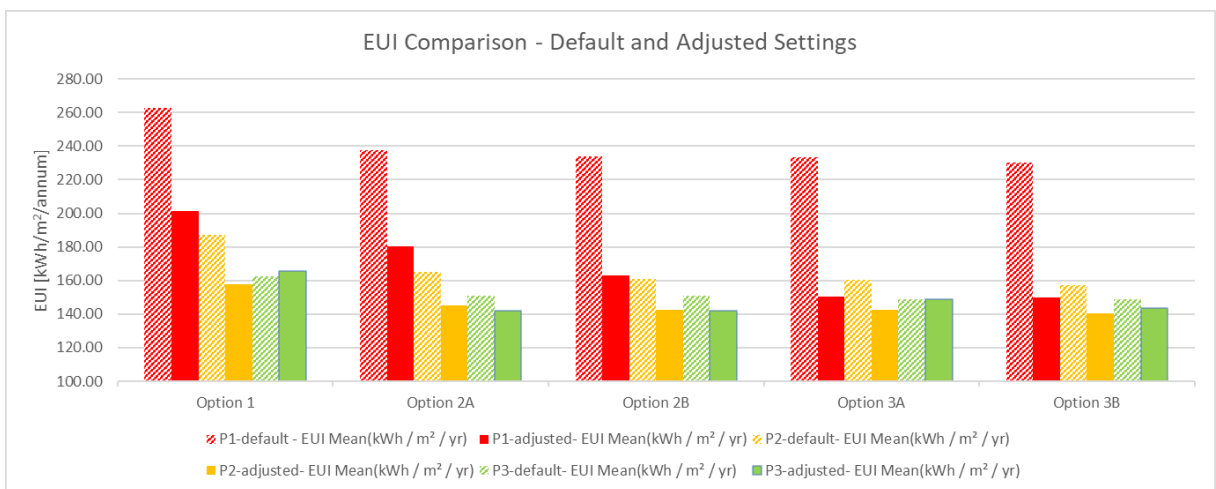


Figure 186: Comparison of EUI of variable design options of models with default and adjusted settings

Referring to the results of all models and trials, it seems that they show similar distribution of the results. Assuming that the models with adjusted settings represent a closer simulation of the dwellings, regarding their operating schedule, lighting equipment and efficiency, they were considered as the final models in order to proceed with further analysis.

Table 29: Summary of Energy Use Intensity of Alternative Design options of models

Design Name	P1			P2			P3		
	EUI	Reduction		EUI	Reduction		EUI	Reduction	
	$kWh/m^2/a$	%		$kWh/m^2/a$	%		$kWh/m^2/a$	%	
Option 1	201.34			157.96			165.83		
Option 2A	180.35	20.99	10.42%	145.33	12.62	7.99%	141.80	24.03	14.49%
Option 2B	162.80	17.55	9.73%	142.27	3.07	2.11%	N/A	N/A	N/A
Option 3A	150.57	12.23	7.51%	142.60	-0.33	-0.23%	148.77	-6.97	-4.92%
Option 3B	149.64	0.93	0.62%	140.61	1.99	1.39%	143.45	5.32	3.57%

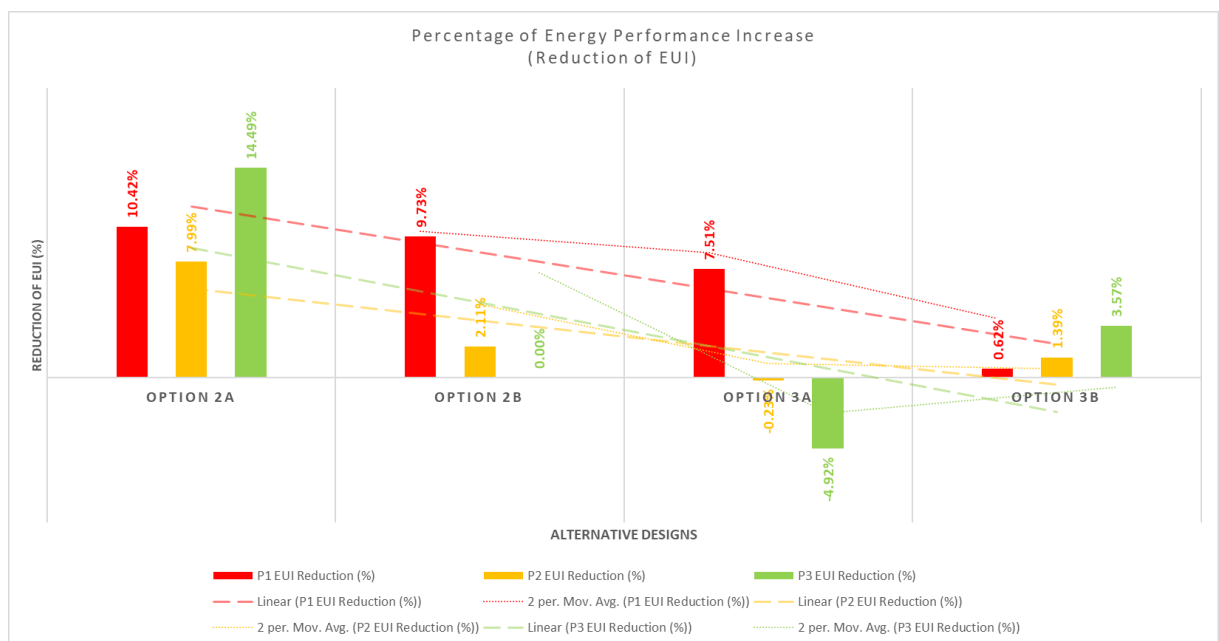


Figure 187: Increase of Energy Performance (%)

Chapter 5

Economic Analysis

5.1. Cost of Interventions

Despite the proven favorable conditions that users receive as a result of the improvement of the energy performance of their premises, one significant deterrent to the implementation of any measures is usually the cost, and in particular the initial investment cost.

However, even if a relatively high initial investment cost, the overall enhancement of energy performance of a residence is in the long run beneficial to the user, both economically but also in life quality and well-being, since it offer better living conditions and thermal comfort in the indoor environment.

As also referred in the previous chapter, the existing thermal conditions of a building and its architectural design are major parameters affecting the results of any measures, or even the proper measures required on each case in order to apply the optimum combination. Thus, the amount of the initial cost depends and is altered according to the optimum measures of each project, meaning that a requirement for a higher cost is met in the older non-insulated dwellings, which is proportionally reduced according to the construction period, reaching the lowest amount in the dwellings constructed during the latest period. Yet should be emphasized that the investment cost is significantly reduced

when measures are part of the initial design and are applied during the construction stage of the building. Under those circumstances, more favourable results can be obtained since more options and of greater significance can be available.

5.2. Cost Estimation

In order to evaluate the feasibility and possible benefits of each design option proposed in Chapter 4 the total investment cost has to be estimated. To this end, the cost of each measure mentioned in the previous chapter is estimated, according to pricing data acquired from the local construction industry and from the pricing assumptions used by the local authority for setting the minimum energy performance requirements at cost optimal levels. (Annex V(Ministry of Commerce, Industry and Tourism, 2013))

Table 30: Pricing Assumptions for the calculation of Proposed Measures

Option	Description of Intervention	Unit	Cost (€/m²)
2A	Addition of 5cm thickness thermal Insulation on External Walls	m ²	35.5
	Addition of 5cm thickness thermal Insulation on Exposed Roof	m ²	12.6
2B	Replacement of windows with double glazing (low-E) and frame with thermal break	m ²	234
3A	Addition of 10cm thickness thermal Insulation on External Walls	m ²	45
	Addition of 10cm thickness thermal Insulation on Exposed Roof	m ²	20
3B	Replacement of windows with triple glazing and frame with thermal break	m ²	327.6

Thus, by estimating the total area of the elements that would be enhanced using the material schedule tool of Revit, the total cost for each intervention on each model is estimated as shown in the following tables.

5.2.1 Model P1: Calculation of Investment for Interventions

The investment cost of interventions named Option 2 and Option 3 is estimated at around €20,000.00 and €27,000.00 respectively, as shown in Table 31 and Table 32 below.

Table 31: Model P1- Estimation of element quantities

	Element	Type Area (m ²)	Element Area (m ²)
1	Walls		304
	a. External Brick Walls of 200mm thickness	175	
	b. External Brick Wall of 250mm thickness with 50mm gap	62	
	c. Internal Brick Wall of 250mm thickness with 50mm gap	67	
2	Roof	76	76
3	Exterior Aluminum Sliding Windows and Doors	36.27	36.27

Table 32: Model P3- Investment Cost Breakdown of Proposed Measures

Option	Description of Intervention	Unit	Price (€/m ²)	Quantity	Cost (€)
2A	Addition of 5cm thickness thermal Insulation on External Walls	m ²	35.5	304	10,792.00
	Addition of 5cm thickness thermal Insulation on Exposed Roof	m ²	12.6	76	957.60
Total Cost of Option 2A					€11,749.60
2B	Replacement of windows with double glazing (low-E) and frame with thermal break	m ²	234	36.27	8,487.18

Total Cost of Option 2B					€8,487.18
Total Cost of Option 2 (2A+2B)					€20,236.78
3A	Addition of 10cm thickness thermal Insulation on External Walls	m ²	45	304	13,680.00
	Addition of 10cm thickness thermal Insulation on Exposed Roof	m ²	20	76	1,520
Total Cost of Option 3A					€15,200.00
3B	Replacement of windows with triple glazing and frame with thermal break	m ²	327.6	36.27	11,882.05
Total Cost of Option 3B					€11,882.05
Total Cost of Option 3 (3A+3B)					€27,082.05

5.2.2 Model P₂: Calculation of Investment for Interventions

The investment cost of interventions named Option 2 and Option 3 is estimated at around €13,000.00 and €17,500.00 respectively, as shown in Table 33 and Table 34 below:

Table 33: Model P₂- Estimation of element quantities

	Element	Type Area (m²)	Element Area (m²)
1	Walls		204
	a. External Brick Walls of 200mm thickness	131	
	b. External Brick Wall of 250mm thickness	73	
2	Roof	49	49
3	Exterior Aluminum Sliding Windows and Doors	22.89	22.89

Table 34: Model P₂- Investment Cost Breakdown of Proposed Measures

Option	Description of Intervention	Unit	Price (€/m ²)	Quantity	Cost (€)
2A	Addition of 5cm thickness thermal Insulation on External Walls	m ²	35.5	204	7,242.00
	Addition of 5cm thickness thermal Insulation on Exposed Roof	m ²	12.6	49	617.40
Total Cost of Option 2A					€7,859.40
2B	Replacement of windows with double glazing (low-E) and frame with thermal break	m ²	234	22.89	5,356.26
Total Cost of Option 2B					€5,356.26
Total Cost of Option 2 (2A+2B)					€13,215.66
3A	Addition of 10cm thickness thermal Insulation on External Walls	m ²	45	204	9,180.00
	Addition of 10cm thickness thermal Insulation on Exposed Roof	m ²	20	49	980.00
Total Cost of Option 3A					€10,160.00
3B	Replacement of windows with triple glazing and frame with thermal break	m ²	327.6	22.89	7,498.76
Total Cost of Option 3B					€7,498.76
Total Cost of Option 3 (3A+3B)					€17,658.76

5.2.3 Model P₃: Calculation of Investment for Interventions

The investment cost of interventions named Option 2 and Option 3 is estimated at around €7,859.40 and €13,447.40 respectively, as shown in Table 35 and Table 36 below.

Table 35: Model P₃- Estimation of element quantities

	Element	Type Area (m²)	Element Area (m²)
1	Walls		192
	a. External Brick Walls of 250mm thickness	135	
	b. Internal Brick Wall of 250mm thickness	56	
2	Roof	52	52
3	Exterior Aluminum Sliding Windows and Doors	11.50	11.50

Table 36: Model P₂- Investment Cost Breakdown of Proposed Measures

Option	Description of Intervention	Unit	Price (€/m²)	Quantity	Cost (€)
2A	Addition of 5cm thickness thermal Insulation on External Walls	m ²	35.5	192	6,816.00
	Addition of 5cm thickness thermal Insulation on Exposed Roof	m ²	12.6	52	655.20
Total Cost of Option 2A					€7,859.40
2B	Replacement of windows with double glazing (low-E) and frame with thermal break	m ²	234	0	0.00
Total Cost of Option 2B					€0.00
Total Cost of Option 2 (2A+2B)					€7,859.40

3A	Addition of 10cm thickness thermal Insulation on External Walls	m ²	45	192	8,640.00
	Addition of 10cm thickness thermal Insulation on Exposed Roof	m ²	20	52	1040.00
Total Cost of Option 3A					€9,680.00
3B	Replacement of windows with triple glazing and frame with thermal break	m ²	327.6	11.50	3,767.40
Total Cost of Option 3B					€3,767.40
Total Cost of Option 3 (3A+3B)					€13,447.40

5.3. Calculation of Annual Energy Savings

Despite the difference observed on the models due to the latest adjustment on Energy Settings (section 4.8), the energy demand reduction declination was proportional in all trials of the models. Thus, the energy cost estimated by Revit in the first trials is taken on mind to evaluate economically the above interventions. The cost of energy was assumed equal to €0.185 per kWh, according to information acquired by the local electricity authority for the latest years. ([Electricity Authority Cyprus -EAC](#))

5.3.1 Model P₁: Annual Energy Savings

The initial annual energy cost of model P₁ under the existing thermal and construction characteristics, is estimated at €46.50/m²(Table 23), indicating an annual cost of €5,347.50 (115m², Table 2). Due to the interventions 2A and 2B (2A+2B) listed on the same table, the cost is reduced to €41.88/m² or €4,816.20 and €41.20/m² or €4,738.00 respectively. Thus, an annual saving of **€610.00** is assumed due to this intervention.

Regarding the interventions 3A and 3B (3A+3B), the estimated annual energy cost is reduced to €41.12/m² or €4,728.80 and €40.48/m² or €4,655.20 respectively, indicating an annual saving amount equal to **€692.30**.

5.3.2 Model P₂: Annual Energy Savings

Analysis for Model P₂ for the existing thermal and construction characteristics, estimates an annual energy cost of €32.49/m²(Table 23), indicating an annual cost of €3,054.06 (94m², Table 4). The annual cost resulted due to interventions 2A and 2B (2A+2B), is estimated at €28.32/m² or €2,662.08 and €27.56/m² or €2,590.64 respectively, allowing the assumption of an annual saving equal to **€463.42** is assumed due to this intervention. In a similar way, the reduction of annual cost due to the final interventions is estimated at **€530.16** (3A: €27.44/m² or €2,579.36 and 3B: €26.85/m² or €2,523.90).

5.3.3 Model P₃: Annual Energy Savings

The annual energy cost of model P₃ at the as built simulation is estimated at €27.28/m²(Table 23), resulting in an annual cost of €2,346.08 (86m², Table 6). The implementation of intervention 2A (2B was applied at the construction stage) causes a declination of the energy demand that forms the annual cost at €25.24/m² or €2,170.64 indicating an annual saving equal to **€175.44**. After implementing the measures named 3A and 3B (3A+3B) to the model, the annual saving amount equals **€203.82**. (3A and 3B: €24.91/m² or €2,142.26).

It is worth mentioned that, as previously stated, the model P₃ had already some energy performance improvement measures applied at the construction stage, being the use of 250mm thermal bridges, addition external insulation on concrete elements and roof, and double (low-e) glazing windows. Thus, interventions 2 and 3 formed a building envelope enhanced with 5cm and 10cm additional external insulation on each element.

Table 37: All Models- Calculation of Annual Savings

Intervention	Investment (€)	Annual Savings (€)
Model P₁		
Option 2	20,200.00	610.00
Option 3	27,100.00	692.00
Model P₂		
Option 2	13,200.00	463.00
Option 3	17,700.00	530.16
Model P₃		
Option 2	7,900.00	175.00
Option 3	13,400.00	204.00

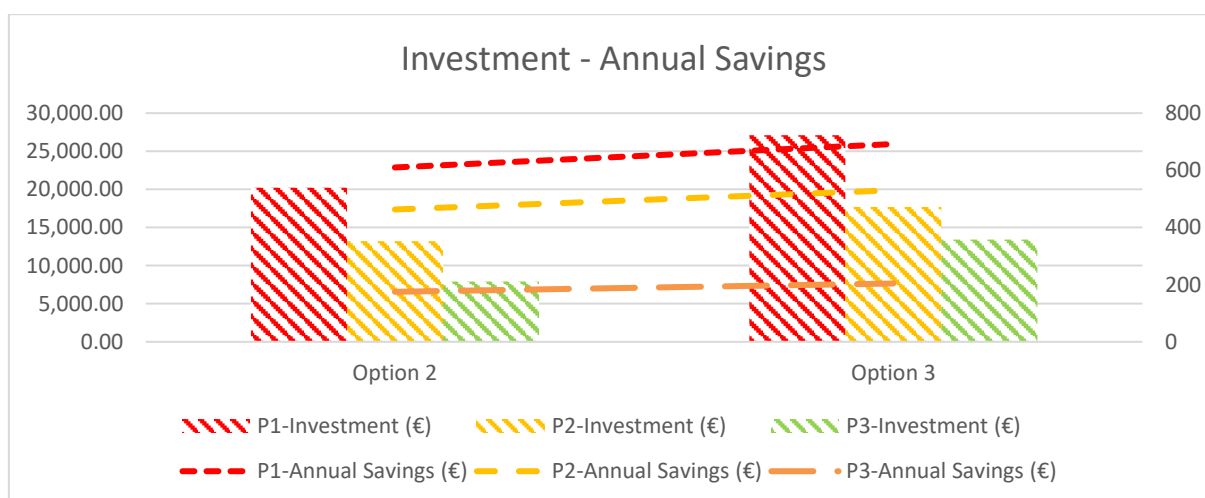


Figure 188: Relation of investment cost and Annual Savings

5.4. Payback Period

The payback period was calculated by assuming a negative value in the cash flow representing the investment cost for each intervention and model, and energy savings considered as inflows. ()

5.4.1 Model P₁

P₁-Option 2

Table 38: P₁-Option 2- Calculation of Payback Period

r		11%			
Year	Cash Flow	Expenses	Cash flow	PV CF	Balance
0	€0.00	-€20,200.00	-€20,200.00	-€20,200.00	-€20,200.00
1	€610.00		€610.00	€549.55	-€19,650.45
2	€610.00		€610.00	€495.09	-€19,155.36
3	€610.00		€610.00	€446.03	-€18,709.33
4	€610.00		€610.00	€401.83	-€18,307.51
5	€610.00		€610.00	€362.01	-€17,945.50
6	€610.00		€610.00	€326.13	-€17,619.37
7	€610.00		€610.00	€293.81	-€17,325.56
8	€610.00		€610.00	€264.70	-€17,060.87
9	€610.00		€610.00	€238.46	-€16,822.40
10	€610.00		€610.00	€214.83	-€16,607.57
11	€610.00		€610.00	€193.54	-€16,414.03
12	€610.00		€610.00	€174.36	-€16,239.66

13	€610.00	€610.00	€157.08	-€16,082.58
14	€610.00	€610.00	€141.52	-€15,941.06
15	€610.00	€610.00	€127.49	-€15,813.57
16	€610.00	€610.00	€114.86	-€15,698.71
17	€610.00	€610.00	€103.48	-€15,595.24
18	€610.00	€610.00	€93.22	-€15,502.01
19	€610.00	€610.00	€83.98	-€15,418.03
20	€610.00	€610.00	€75.66	-€15,342.37
21	€610.00	€610.00	€68.16	-€15,274.21
22	€610.00	€610.00	€61.41	-€15,212.80
23	€610.00	€610.00	€55.32	-€15,157.48
24	€610.00	€610.00	€49.84	-€15,107.64
25	€610.00	€610.00	€44.90	-€15,062.74
26	€610.00	€610.00	€40.45	-€15,022.28
27	€610.00	€610.00	€36.44	-€14,985.84
28	€610.00	€610.00	€32.83	-€14,953.01
29	€610.00	€610.00	€29.58	-€14,923.43
30	€610.00	€610.00	€26.65	-€14,896.79

PB

Years

30+

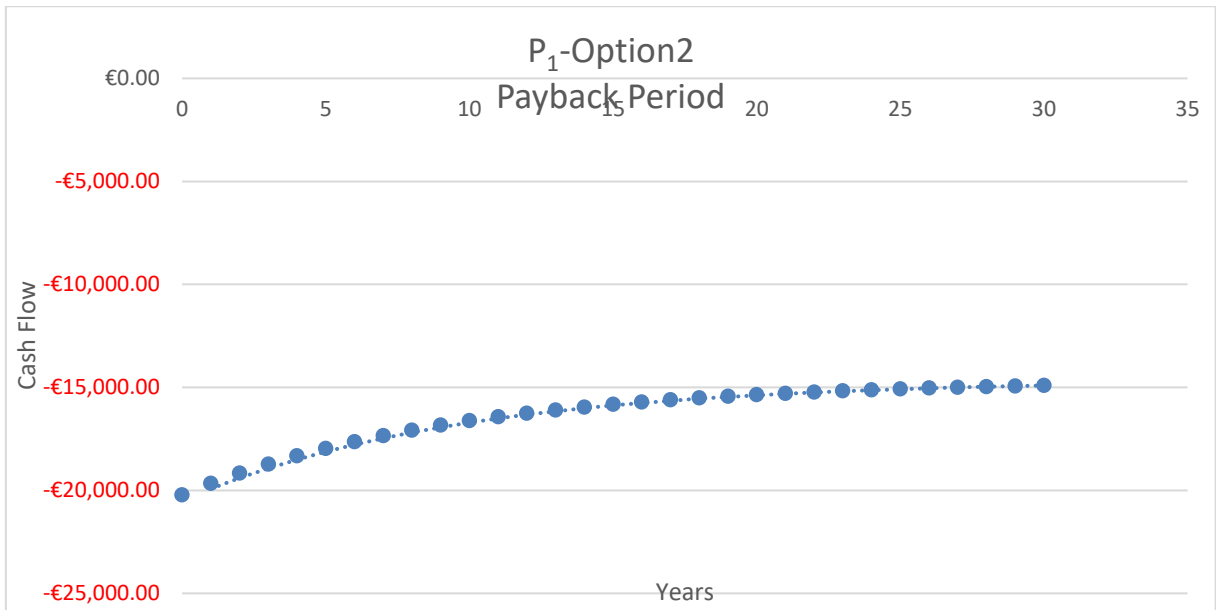


Figure 189: P₁- Option 2 Payback Period

P₁- Option 3

Table 39: P₁-Option 3- Calculation of Payback Period

Year	Cash Flow	Expenses	Cash flow	PV CF	Balance
0	€0.00	-€27,100.00	-€27,100.00	-€27,100.00	-€27,100.00
1	€692.00		€692.00	€623.42	-€26,476.58
2	€692.00		€692.00	€561.64	-€25,914.93
3	€692.00		€692.00	€505.98	-€25,408.95
4	€692.00		€692.00	€455.84	-€24,953.11
5	€692.00		€692.00	€410.67	-€24,542.44
6	€692.00		€692.00	€369.97	-€24,172.47
7	€692.00		€692.00	€333.31	-€23,839.16
8	€692.00		€692.00	€300.28	-€23,538.88

9	€692.00	€692.00	€270.52	-€23,268.36
10	€692.00	€692.00	€243.71	-€23,024.65
11	€692.00	€692.00	€219.56	-€22,805.09
12	€692.00	€692.00	€197.80	-€22,607.29
13	€692.00	€692.00	€178.20	-€22,429.09
14	€692.00	€692.00	€160.54	-€22,268.55
15	€692.00	€692.00	€144.63	-€22,123.92
16	€692.00	€692.00	€130.30	-€21,993.62
17	€692.00	€692.00	€117.39	-€21,876.23
18	€692.00	€692.00	€105.75	-€21,770.48
19	€692.00	€692.00	€95.27	-€21,675.21
20	€692.00	€692.00	€85.83	-€21,589.38
21	€692.00	€692.00	€77.33	-€21,512.05
22	€692.00	€692.00	€69.66	-€21,442.39
23	€692.00	€692.00	€62.76	-€21,379.63
24	€692.00	€692.00	€56.54	-€21,323.09
25	€692.00	€692.00	€50.94	-€21,272.15
26	€692.00	€692.00	€45.89	-€21,226.26
27	€692.00	€692.00	€41.34	-€21,184.92
28	€692.00	€692.00	€37.24	-€21,147.68
29	€692.00	€692.00	€33.55	-€21,114.12
30	€692.00	€692.00	€30.23	-€21,083.90
11	PB	Years		30+

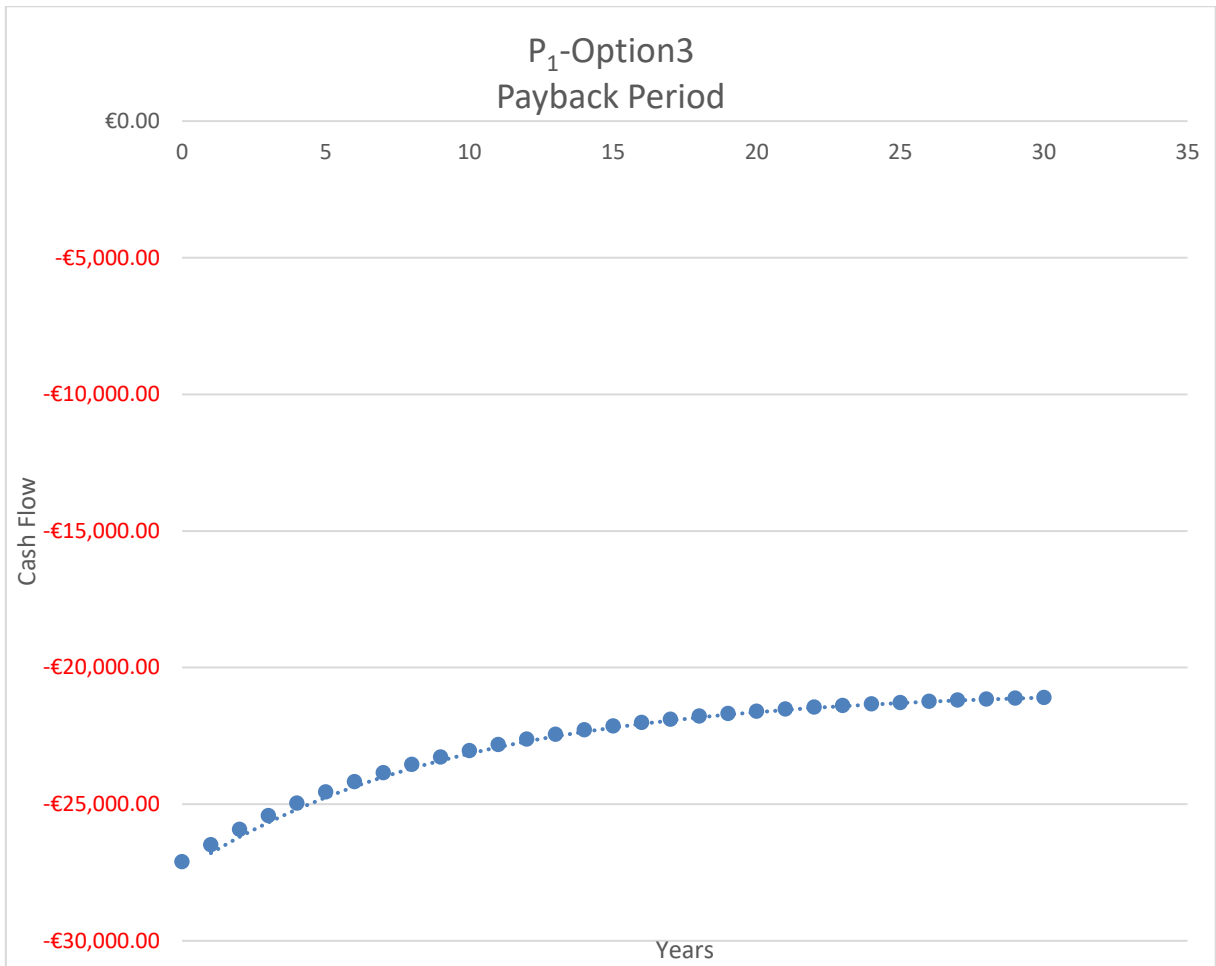


Figure 190: P1- Option 3 Payback Period

5.4.2 Model P₂

P₂- Option 2

Table 40: P₂-Option 2- Calculation of Payback Period

Year	Cash Flow	Expenses	Cash flow	PV CF	Balance
0	€0.00	-€13,200.00	-€13,200.00	-€13,200.00	-€13,200.00
1	€463.00		€463.00	€417.12	-€12,782.88
2	€463.00		€463.00	€375.78	-€12,407.10

3	€463.00	€463.00	€338.54	-€12,068.56
4	€463.00	€463.00	€304.99	-€11,763.57
5	€463.00	€463.00	€274.77	-€11,488.80
6	€463.00	€463.00	€247.54	-€11,241.26
7	€463.00	€463.00	€223.01	-€11,018.25
8	€463.00	€463.00	€200.91	-€10,817.35
9	€463.00	€463.00	€181.00	-€10,636.35
10	€463.00	€463.00	€163.06	-€10,473.29
11	€463.00	€463.00	€146.90	-€10,326.38
12	€463.00	€463.00	€132.34	-€10,194.04
13	€463.00	€463.00	€119.23	-€10,074.81
14	€463.00	€463.00	€107.41	-€9,967.40
15	€463.00	€463.00	€96.77	-€9,870.63
16	€463.00	€463.00	€87.18	-€9,783.45
17	€463.00	€463.00	€78.54	-€9,704.91
18	€463.00	€463.00	€70.76	-€9,634.15
19	€463.00	€463.00	€63.74	-€9,570.41
20	€463.00	€463.00	€57.43	-€9,512.98
21	€463.00	€463.00	€51.74	-€9,461.24
22	€463.00	€463.00	€46.61	-€9,414.63
23	€463.00	€463.00	€41.99	-€9,372.64
24	€463.00	€463.00	€37.83	-€9,334.81
25	€463.00	€463.00	€34.08	-€9,300.73
26	€463.00	€463.00	€30.70	-€9,270.03

27	€463.00	€463.00	€27.66	-€9,242.37
28	€463.00	€463.00	€24.92	-€9,217.45
29	€463.00	€463.00	€22.45	-€9,195.00
30	€463.00	€463.00	€20.23	-€9,174.77
	PB	Years		30+

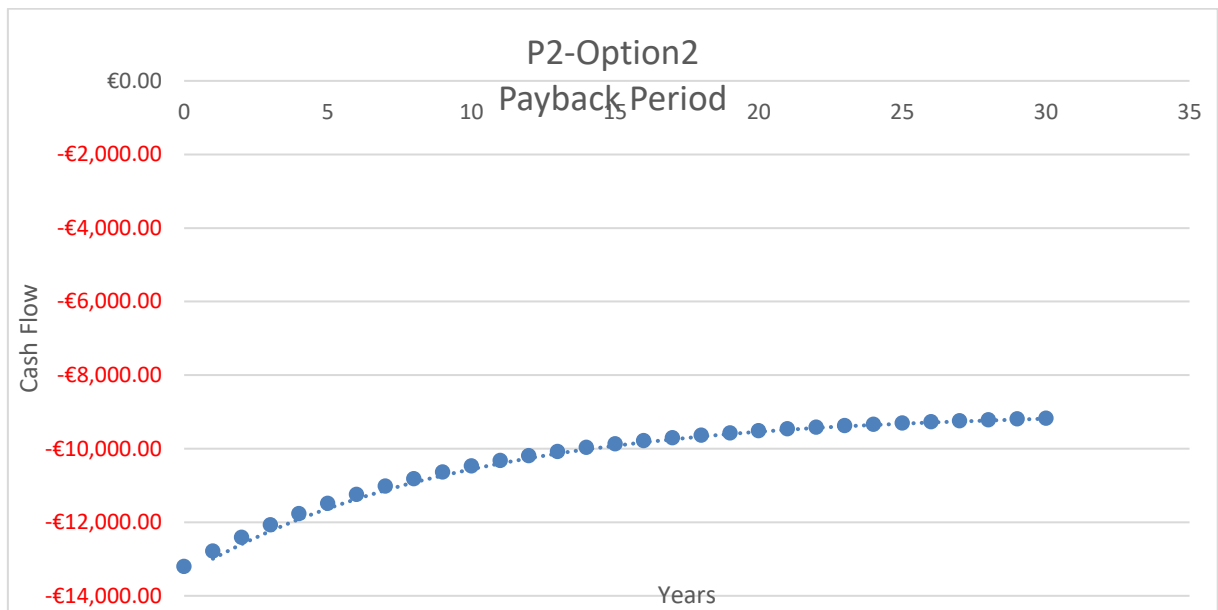


Figure 191: P₂- Option 2 Payback Period

P₂- Option 3

Table 41: P₂-Option 3- Calculation of Payback Period

r	11%				
Year	Cash Flow	Expenses	Cash flow	PV CF	Balance
0	€0.00	-€17,700.00	-€17,700.00	-€17,700.00	-€17,700.00
1	€530.16		€530.16	€477.62	-€17,222.38

2	€530.16	€530.16	€430.29	-€16,792.09
3	€530.16	€530.16	€387.65	-€16,404.44
4	€530.16	€530.16	€349.23	-€16,055.21
5	€530.16	€530.16	€314.62	-€15,740.58
6	€530.16	€530.16	€283.45	-€15,457.14
7	€530.16	€530.16	€255.36	-€15,201.78
8	€530.16	€530.16	€230.05	-€14,971.73
9	€530.16	€530.16	€207.25	-€14,764.48
10	€530.16	€530.16	€186.71	-€14,577.76
11	€530.16	€530.16	€168.21	-€14,409.55
12	€530.16	€530.16	€151.54	-€14,258.01
13	€530.16	€530.16	€136.52	-€14,121.49
14	€530.16	€530.16	€122.99	-€13,998.49
15	€530.16	€530.16	€110.81	-€13,887.69
16	€530.16	€530.16	€99.82	-€13,787.86
17	€530.16	€530.16	€89.93	-€13,697.93
18	€530.16	€530.16	€81.02	-€13,616.91
19	€530.16	€530.16	€72.99	-€13,543.92
20	€530.16	€530.16	€65.76	-€13,478.16
21	€530.16	€530.16	€59.24	-€13,418.92
22	€530.16	€530.16	€53.37	-€13,365.55
23	€530.16	€530.16	€48.08	-€13,317.47
24	€530.16	€530.16	€43.32	-€13,274.15
25	€530.16	€530.16	€39.02	-€13,235.13

26	€530.16	€530.16	€35.16	-€13,199.97
27	€530.16	€530.16	€31.67	-€13,168.30
28	€530.16	€530.16	€28.53	-€13,139.76
29	€530.16	€530.16	€25.71	-€13,114.06
30	€530.16	€530.16	€23.16	-€13,090.90
	PB	Years		30+

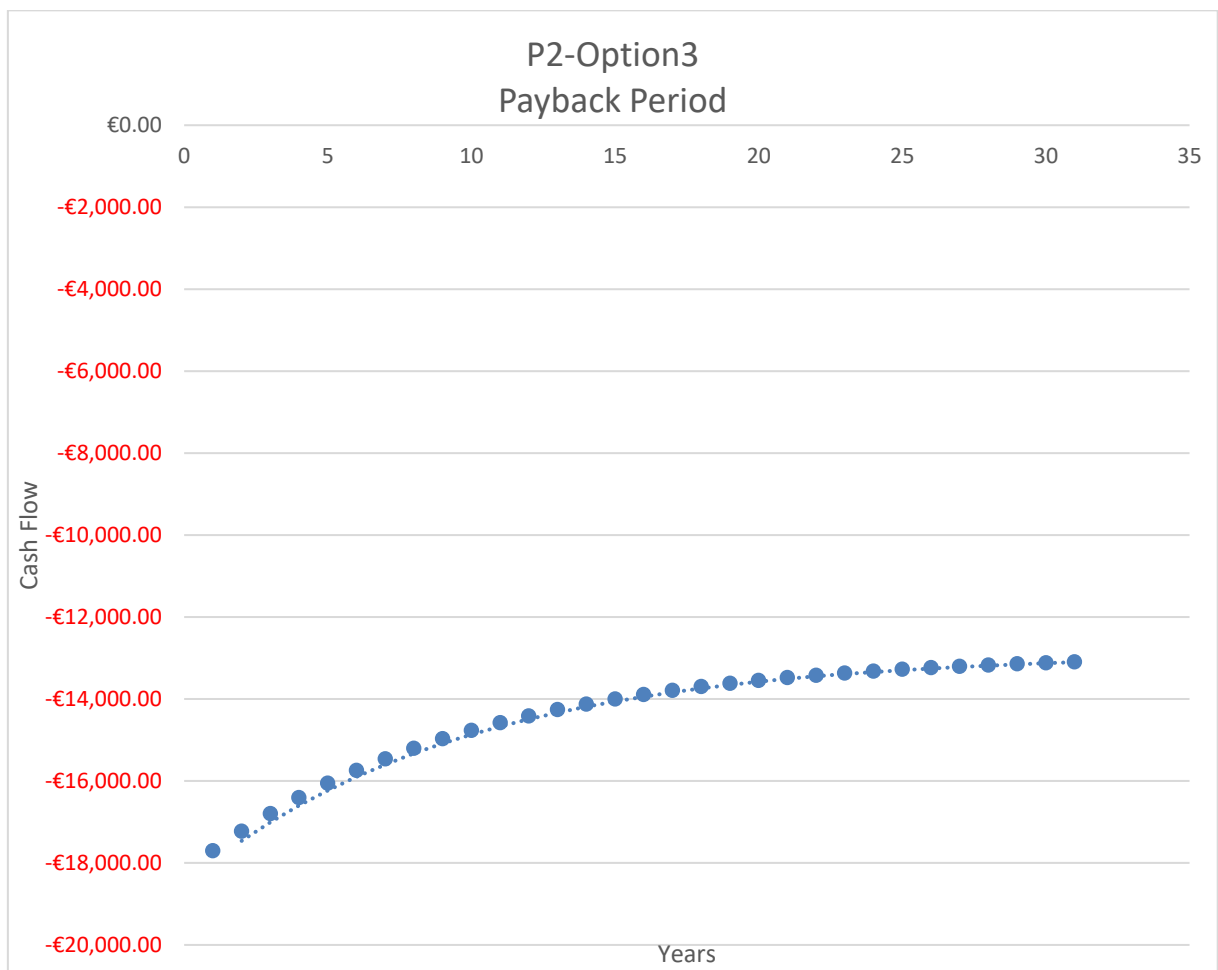


Figure 192: P₂- Option 3 Payback Period

5.4.3 Model P₃

P₃- Option 2

Table 42: P₃-Option 2 Calculation of Payback Period

r		11%			
Year	Cash Flow	Expenses	Cash flow	PV CF	Balance
0	€0.00	-€7,900.00	-€7,900.00	-€7,900.00	-€7,900.00
1	€175.00		€175.00	€157.66	-€7,742.34
2	€175.00		€175.00	€142.03	-€7,600.31
3	€175.00		€175.00	€127.96	-€7,472.35
4	€175.00		€175.00	€115.28	-€7,357.07
5	€175.00		€175.00	€103.85	-€7,253.22
6	€175.00		€175.00	€93.56	-€7,159.66
7	€175.00		€175.00	€84.29	-€7,075.37
8	€175.00		€175.00	€75.94	-€6,999.43
9	€175.00		€175.00	€68.41	-€6,931.02
10	€175.00		€175.00	€61.63	-€6,869.38
11	€175.00		€175.00	€55.52	-€6,813.86
12	€175.00		€175.00	€50.02	-€6,763.84
13	€175.00		€175.00	€45.06	-€6,718.77
14	€175.00		€175.00	€40.60	-€6,678.17
15	€175.00		€175.00	€36.58	-€6,641.60
16	€175.00		€175.00	€32.95	-€6,608.65
17	€175.00		€175.00	€29.69	-€6,578.96

18	€175.00	€175.00	€26.74	-€6,552.22
19	€175.00	€175.00	€24.09	-€6,528.12
20	€175.00	€175.00	€21.71	-€6,506.42
21	€175.00	€175.00	€19.55	-€6,486.86
22	€175.00	€175.00	€17.62	-€6,469.25
23	€175.00	€175.00	€15.87	-€6,453.37
24	€175.00	€175.00	€14.30	-€6,439.08
25	€175.00	€175.00	€12.88	-€6,426.19
26	€175.00	€175.00	€11.60	-€6,414.59
27	€175.00	€175.00	€10.45	-€6,404.13
28	€175.00	€175.00	€9.42	-€6,394.72
29	€175.00	€175.00	€8.49	-€6,386.23
30	€175.00	€175.00	€7.64	-€6,378.59
	PB	Years		30+

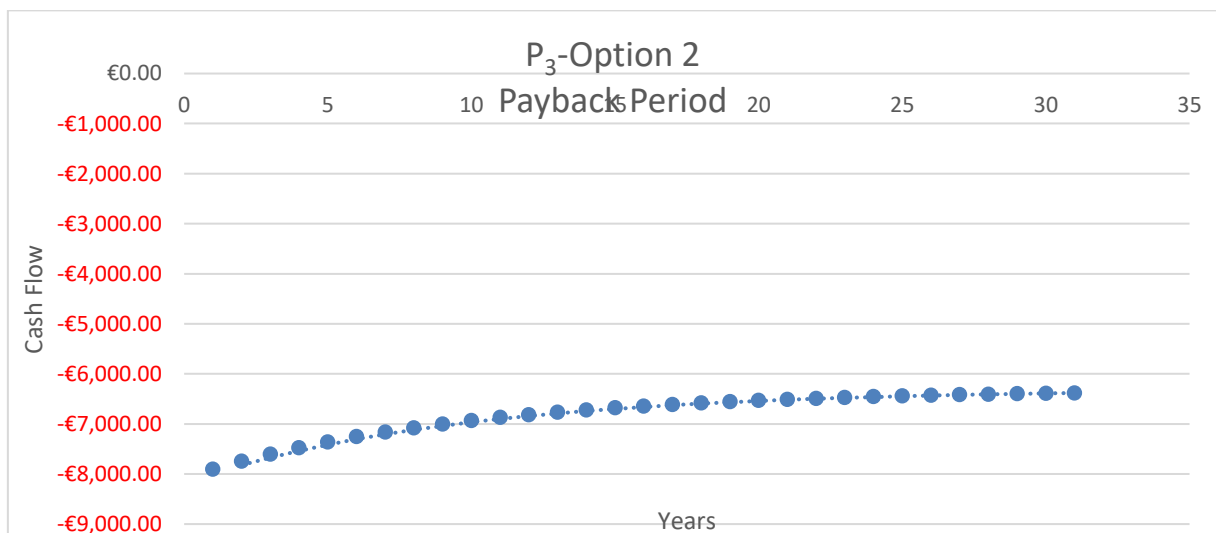


Figure 193: P₃- Option 2 Payback Period

P₃- Option 3

Table 43: P₃-Option 3 Calculation of Payback Period

r	11%				
Year	Cash Flow	Expenses	Cash flow	PV CF	Balance
0	€0.00	-€13,400.00	-€13,400.00	-€13,400.00	-€13,400.00
1	€204.00		€204.00	€183.78	-€13,216.22
2	€204.00		€204.00	€165.57	-€13,050.65
3	€204.00		€204.00	€149.16	-€12,901.48
4	€204.00		€204.00	€134.38	-€12,767.10
5	€204.00		€204.00	€121.06	-€12,646.04
6	€204.00		€204.00	€109.07	-€12,536.97
7	€204.00		€204.00	€98.26	-€12,438.71
8	€204.00		€204.00	€88.52	-€12,350.19
9	€204.00		€204.00	€79.75	-€12,270.44
10	€204.00		€204.00	€71.85	-€12,198.60
11	€204.00		€204.00	€64.73	-€12,133.87
12	€204.00		€204.00	€58.31	-€12,075.56
13	€204.00		€204.00	€52.53	-€12,023.03
14	€204.00		€204.00	€47.33	-€11,975.70
15	€204.00		€204.00	€42.64	-€11,933.06
16	€204.00		€204.00	€38.41	-€11,894.65
17	€204.00		€204.00	€34.61	-€11,860.05
18	€204.00		€204.00	€31.18	-€11,828.87

19	€204.00	€204.00	€28.09	-€11,800.78
20	€204.00	€204.00	€25.30	-€11,775.48
21	€204.00	€204.00	€22.80	-€11,752.69
22	€204.00	€204.00	€20.54	-€11,732.15
23	€204.00	€204.00	€18.50	-€11,713.65
24	€204.00	€204.00	€16.67	-€11,696.98
25	€204.00	€204.00	€15.02	-€11,681.96
26	€204.00	€204.00	€13.53	-€11,668.44
27	€204.00	€204.00	€12.19	-€11,656.25
28	€204.00	€204.00	€10.98	-€11,645.27
29	€204.00	€204.00	€9.89	-€11,635.38
30	€204.00	€204.00	€8.91	-€11,626.47
	PB	Years		30+

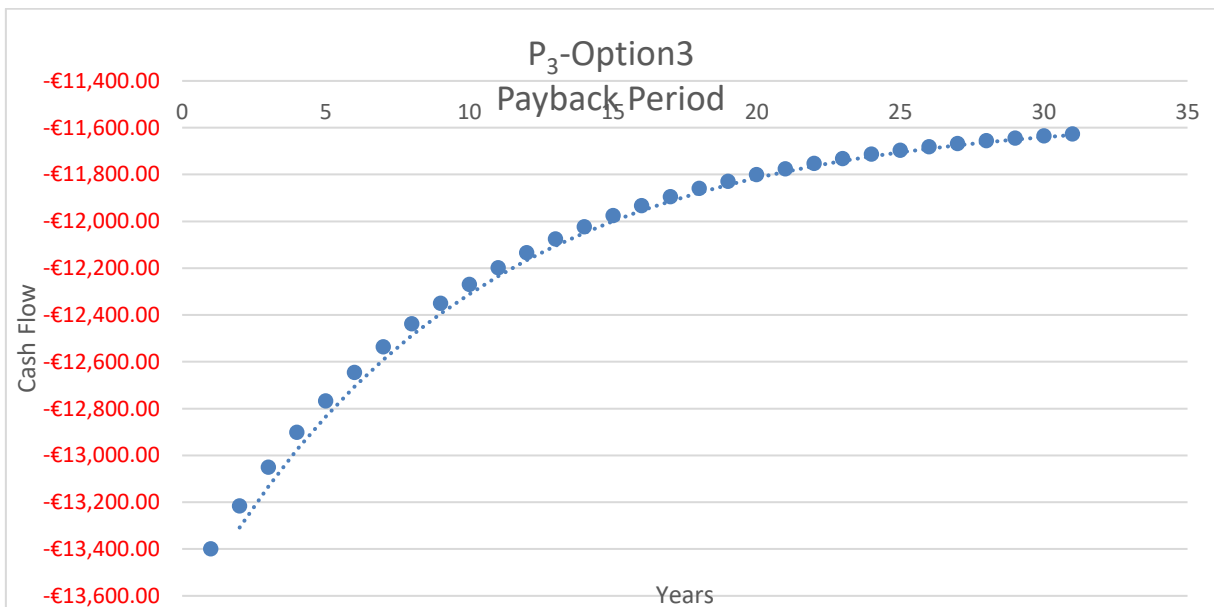


Figure 194: P3- Option 3 Payback Period

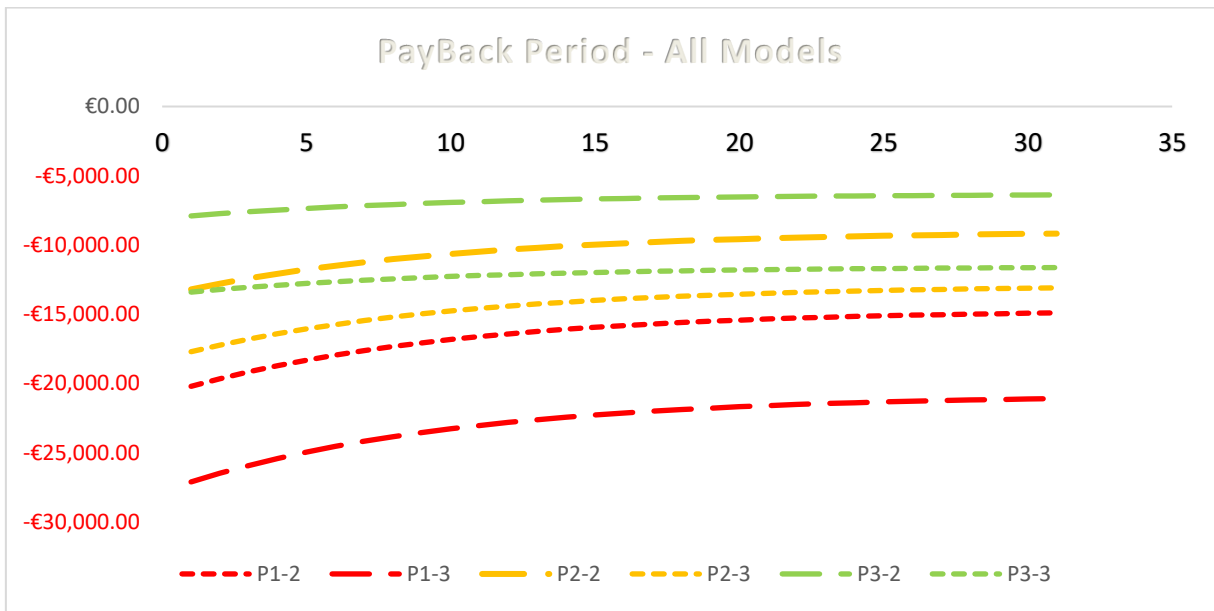


Figure 195: All Models- Payback Period

5.4.4 Trial Case: Add Renewables – Ignore Present Value

If taking as example on Revit simulation the model P2, intervention namely Option 2B and assuming PVs at 75% coverage factor of panel efficiency 20.4%, the Insight 360 energy analysis indicates a reduction of €19.5/m² on annual energy cost. Thus, an additional annual reduction of €2,250.00 can be assumed on the model. However, to get that reduction, an additional investment of about €20,000.00 is required for the PV panels (estimated capacity required about 12kW, price assumed equal to €1700/kW (Ministry of Commerce, Industry and Tourism, 2013))

The payback period for the investment for the interventions on the models is around 25-35 years, if not taking into account the Present Value factor. Taking as example the model mentioned above, Payback Period for the interventions of Option 2, is equal to 28 years. It should be emphasized that the period is reduced significantly (12 years) by the use of renewables, despite the higher initial cost.

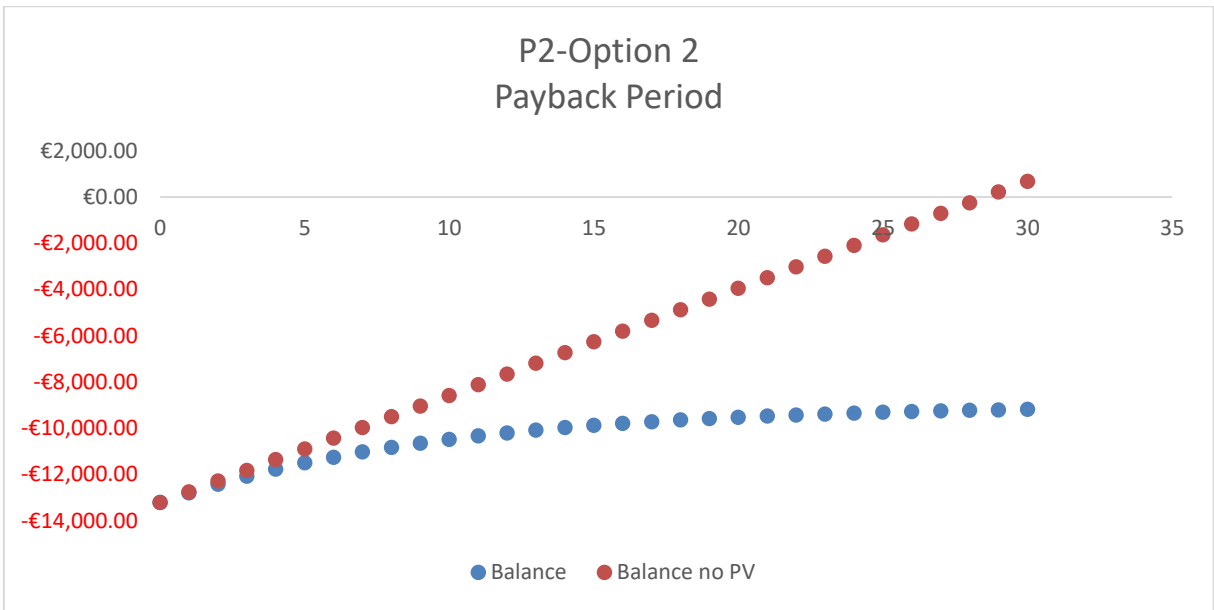


Figure 196: P2 Option 2 Trial (no present Value)- Payback Period

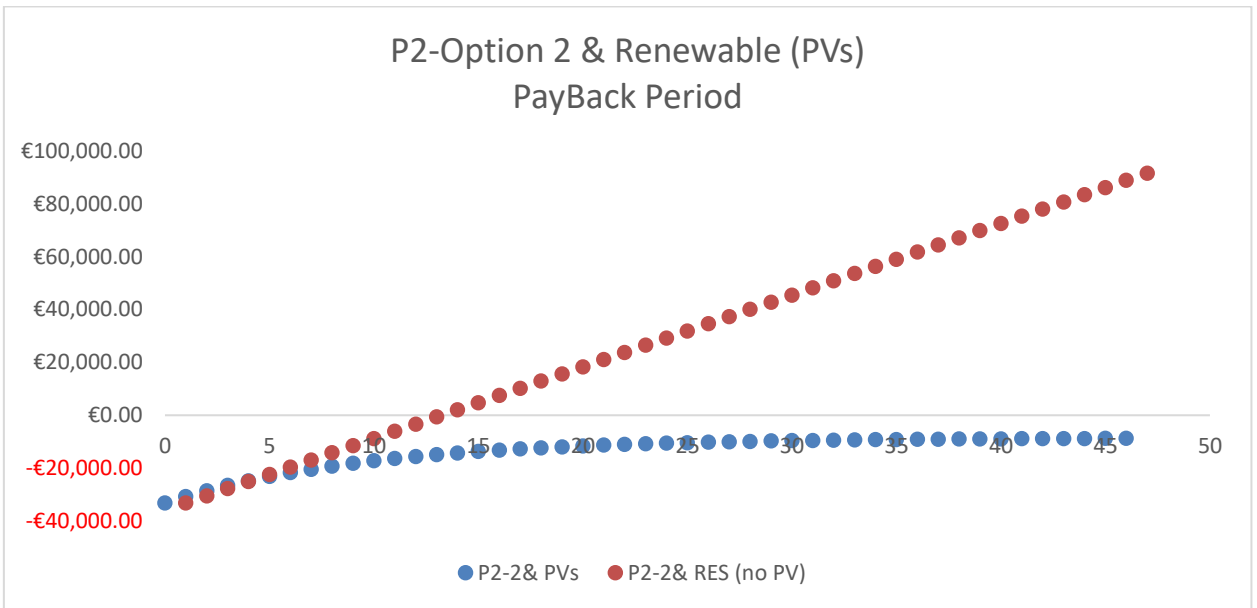


Figure 197: P2 Option 2 & Addition of Renewable Energy Sources Trial (no present Value)- Payback Period

Chapter 6

Results and Discussion

6.1. Objective and Outcomes of the Study

The main objective of the study had to do with the creation of Building Information Models of selected single-family dwellings constructed in different chronological periods, having different structural and thermal characteristics, that would be used to create energy models, and apply proposed enhancement measures, aiming to improve their energy performance. The applied measures would be assessed in order to identify the parameters that require more attention and lead to more efficient improvements, and evaluated both technically and economically, ending up with highlighting the optimum enhancement option for each dwelling.

Based on preliminary estimations, the target of the several alternative design had been to reach an annual Energy Use Intensity below 50kWh/m² per the definition of a Zero Energy Building, through improvements on the building envelope. The remaining Energy Demand would be covered with Renewable Energy Sources such as PVs, aiming on a dwelling with Zero Energy Demand from conventional fuel.

However, the initial expectation were not fulfilled, since the lowest annual Energy Use Intensity value of the models obtained from the energy analysis was ranging around

140kWh/m². Nevertheless, significant conclusions can be still drawn, based on the reduction values observed and as discussed below.

6.2. Overall Reduction of Energy Use Intensity

Excluding the issues met on the last analysis of the model of category P₃, improvements on the buildings performance appear under all design alternatives. Highest values though are observed in the first design option (2A), which represent the addition of 5cm thick external insulation. An emphasis should be given in the fact that a highest reduction value appears on the P₃ model under option 2A, while P₁ model shows significant improvements under options 2A, 2B and 3A (Table 29).

Note that the design option 2A for model P₃ represents a 25cm brick wall with totally 8cm thickness external insulation, roof construction consisting of 18 cm concrete slab, 10 cm screed and 10cm external insulation, and double low-e glazing windows, while a similar envelope for model P₁ can be met under design option 3A (20cm Brick Walls with 10cm external insulation, roof of 15cm concrete slab, 10cm screed and 10cm external insulation, and double low-e glazing windows). Improvements are also met in model P₂, but in a lower magnitude, coming out from the lower initial energy use intensity values due to the improved architectural design.

Thus, it can be concluded that a favorable design option for similar dwellings under close climatic conditions would be the application of the enhancements, which would result in improvements ranging from 15% to already lightly insulated dwellings to even 28% on non-insulated dwellings. Additionally, by model P₂, the importance of the proper architectural design is emphasized, since lowest initial energy use intensity values are met, but also lower improvement potential, lying around 10%.

Wall and Roof Construction

Based on the insights performed at the web-based tool (Insight 360 - <https://insight.autodesk.com/oneenergy>), especially the roof but also the wall type of construction consist of very significant parameters in improving the overall buildings performance. Improvement potential of model P₁ is estimated at around 30kWh/m²/a through the roof and around 2kWh/m²/a through the walls, which is equal to 15% and

1% respectively. Improvements on roof and wall type on model P2 have a reduction potential of 13kWh/m²/a and 1kWh/m²/a, being equal to around 9% and 0.6% respectively, which even that they are still important, they indicate again the importance of architectural design improvements, leading to lower energy demands and lower thermal losses through the building envelope. Lowest potential is met at model P3, where the roof type alteration can result in just around 1.5kWh/m²/a and minor values due to wall type, totally reaching just around 1.3%. Again, this fact is indicating the importance of the architectural design in combination with minor thermal insulation measures, and the significant results of the implementation of the Energy Performance of Buildings Directive (EPBD) during that period.

6.3. Glazing type

Glazing type can be also considered as an essential improvement in increasing a dwellings energy efficiency. By the results observed due to design option 2B (Table 29), the addition of low-e double glazing windows assisted in around 10% and 2% reductions in energy demand for model P1 and P2 respectively. However, the addition of triple glazing low-e windows offered results of 0.6-3.5% reductions, which can be considered as a minor improvement, in comparison to the double ones.

However, as illustrated by the insights (Insight 360 - <https://insight.autodesk.com/oneenergy>), glazing types offer variable values of energy use intensity modification, according to the orientation applied. While double or triple low-glazing offers reduction on energy demand of the dwelling when used in the proper orientation, it offers no reduction if used in the wrong orientation, or even results in an increased demand, especially when referring to triple low-e glazing.

Hence, selection of the proper glazing at the design stage is a very important task, in order to avoid unnecessary increase of cost for upgraded window types at all orientations of the dwelling, or even avoid results contrary to the expected ones. Similar observations are noted at the Window to Wall ratio (WWR) modifications.

Chapter 7

Recommendations – Further Research

Even though the initial expectations and the main objective of the study was not fulfilled, significant conclusions were still extracted. The initial plan was to simulate an additional fourth model, which would represent a new (non-existing) dwelling, so that more improvements and modifications would be applied. Additionally, the planned techno-economic analysis and feasibility of the proposed measures were not implemented, since the end-up results did not meet the initial expectations.

Although the analyses ended up with some essential indications of the effectiveness of the proposed measures, it is recommended that similar study would be implemented at a later stage, after possible future updates of the employed software. However, accurate results can still be extracted by modifying the design using the default design options in the Insight 360 and Green Building Studio website.

Alternatively, initial indications and benchmarks of the effectiveness of the various design options could be assessed and evaluated by the software, and proceed with another software for the final performance classification.

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