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Deliverable 6.3.2: Short Description

This document contains the study and definition of the baseline period for the three pilot buildings and the analysis of the gathered data aimed to develop accurate and applicable mathematical models to explain the energy consumption with some independent variables such as the outdoor temperature and the solar radiation. Once these energy models are adjusted and validated with real data, they will be used to assess the energy savings achieved with the ECM associated to the deployment of BaaS solution, following the guidelines defined in the IPMVP.

Keywords: IPMVP, baseline period, regression models, accuracy

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Abbreviations and Acronyms

ABE	Adjusted Baseline Energy
BaaS	Building as a Service
CDD	Cooling Degree Day
DoW	Document of Work
DWH	Data Warehouse
ECM	Energy Conservation Measures
ESCO	Energy Services Company
HDD	Heating Degree Day
HVAC	Heating, Ventilation and Air Conditioning
IPMVP	International Performance Measurement and Verification Protocol
KPI	Key Performance Indicator
M&V	Measurement & Verification
RAD	Solar Radiation
R^2	Coefficient of Determination
SE	Standard Error
SES	Sierra Elvira School
WP	Work Package

Executive Summary

The aim of this report is the definition of the baseline period and the development of mathematical models for the energy consumption of the three pilot buildings in some proposed use cases, considering the existing energy systems and meters. The final models here obtained will be applied to evaluate the energy savings related to the implementation of Energy Conservation Measures (ECM) related to the BaaS solution, through a comparison between the baseline period and the reporting period applying the methodology defined in the IPMVP.

The obtained models constitute a fundamental tool for this energy assessment, as they enable the adjustment of the baseline consumption with some independent variables such as weather conditions (outdoor temperature and solar radiation), comfort conditions (indoor temperature), etc.

The first step of the applied methodology is to process and prepare for the following analyses all the data collected from the different meters and sensors implemented in the pilot buildings. Once this step is completed, they should be studied the temporal profiles of the key variables, ranges of values obtained, relations between variables... Finally, using statistic tools, different mathematical models are adjusted to the selected data points of the baseline period. The yielded results are studied, combing energy and statistics criteria, in order to obtain the most accurate and applicable model for the adjusted baseline energy (ABE).

As stated in the DoW, this document will be completed with another report *("D6.3.3: Reporting period")* containing the evaluation of the energy savings resulted from the comparison of the adjusted baseline with the reported measured consumptions.

1 Introduction

The objective of the baseline is to define a reference period to study and develop an accurate mathematical model valid to evaluate the energy savings achieved with the BaaS solution in the three pilot buildings, applying the methodology defined in the IPMVP.

First of all, after this introductory section, the general analysis procedure that has been applied for the regression analysis, based on IPMVP, has been described.

Then, a summary of some of the most representative analysis that have been considered in the three pilot buildings (i.e. CARTIF, ZUB and SES) has been included, describing the use case, independent variables, static factors, modelling period and frequency, mathematical expressions that have been proposed and the regression results and conclusions obtained, finishing with the definitive model that will be used to evaluate the energy savings.

Finally, a summary of the definitive models and the main conclusions drawn are presented.

1.1 Contribution of partners

This task is headed by DALKIA, who is supported and monitored by CARTIF and Fraunhoufer and the rest of research partners.

Partner	Deliverable Focus
DALKIA	Provide the M&V plan for Pilot Buildings to be implemented regarding the baseline, reporting period and basis for adjustment. Use Case definition for SES and M&V plan related to this use case.
CARTIF	Support Dalkia on the Use Cases definition for CARTIF building and M&V plan related with this uses cases.
FHG	Support Dalkia on the Use Cases definition for ZUB building and M&V plan related with this uses cases.

Table 1: Summary of Contributions of Partners

1.2 Relation to other activities in the project

This deliverable continues with the work in the demonstration activities in the project (started in D6.1), and also the Research and Technological Development activities, which aims to the BaaS solution validation and standardization.

Deliverable	Relationship
D1.2	D1.2 established the M&V methodology in order to validate the BaaS solution and the requirements of metering and monitoring for the demonstration buildings
D4.1	D4.1 provided information about the simulation models in the buildings.
D5.1.2	D5.1 identified the Uses Cases and the KPI associated
D6.1	D6.1 selected and provided the information of the demonstration buildings to be adapted in this task

D6.2	D6.2 will be in charge of the analysis of the operation inefficiencies of the demonstration buildings, in order to deploy the M&V plan, baselining and reporting
D6.3.1	D6.3.1 provides the description of the IPMVP Plan.
D6.3.3	D6.3.3 will evaluate the energy savings using the models that have been developed.

Table 2: D6.3 tasks relationship with other BaaS activities

2 Analysis Procedure for the regression analysis based on IPMVP

Once the IPMVP option has been selected and a set of independent variables have been proposed to be studied, the next step is the definition of the analysis procedure that allows developing a valid mathematical model in order to calculate the Adjusted Baseline Energy (ABE), which should include different independent variables and consider the different operation modes, schedules and timetables, periods of the year, etc.

In order to obtain an accurate model, two different kinds of criteria will be used for the decision making regarding the acceptance or rejection of the model: physical and statistical. On the one hand, the model has to be consistent in physical/energy terms. This means that the estimated coefficients for all the different independent variables that are included have to be logical and reasonable regarding the value (order of magnitude) and the sign On the other hand, in order to evaluate the accuracy of a particular regression model (i.e. how well the model defines the relation among the energy consumption and the independent variables), three different statistical tests can be carried out according to the IPMVP methodology: R^2, SE and t-statistic.

The first step to evaluate the accuracy of the model is to study the **coefficient of determination (R^2)**, which represent to what extent the regression model explains the observed variations in the dependent variable Y with respect to its average mean value. Generally, the higher is R^2, the better the model would describe the relation between the independent variables and the dependent variable. Although there is not a universal standard for a minimum acceptable value of R^2, **IPMVP recommends that 75% is a reasonable level for energy modelling**. It is important to remark that the R^2 test is only an initial check. The acceptance or rejection of a model cannot be only based on the R^2. A low level of R^2 indicates that one or more relevant variables have not been included in the model or that its functional form (e.g. linear) is not adequate. It that case, it would be logical to consider other additional independent variables or a different functional form (e.g. quadratic). When a model is used to predict the energy consumption (Y) for a set of independent variables (X_1, X_2, …, X_n), the accuracy is measured with the **standard error (SE) of the estimation**.

Finally, due to the fact that the coefficients of the regression models are statistical estimates of the real relation that exists between an independent variable X and the output Y, they may be subject to the variation. The accuracy of the estimation is measured by the standard error of the coefficient and the associated value of the **t-statistic**. The t-statistic is a statistical test that is used to determine if estimation is statistically significant. Once a value has been estimated with the test, it can be compared with the critical values of the t-distribution, which are tabulated (see *Table 20: t-statistic values in D6.3.1.*). **If the absolute value of the t-statistic is higher than the level indicated in the table, it should be concluded that the estimation is statistically significant**. As a general rule, an absolute value of the t-statistic greater than or equal to 2 implies that the estimated coefficient is significant respect to its standard error and hence there is a concrete relation between Y and X related with this coefficient. Therefore, it can be concluded that the value of the estimated coefficient it is not null. Nevertheless, when the t-statistic is almost 2, the accuracy in the value of the coefficient is around ±100%: too much imprecise in order to assume the value of the coefficient. To obtain a higher accuracy, e.g. ±10%, the t-statistic values should be around 10 or the standard error of the coefficient cannot be higher than 0.1 times the coefficient. Strategies to improve the result of the t-statistic are a good selection of the independent variables, to select those variables that cover a bigger interval, to use more data points for the model, to select a different function for the model, etc.

3 CARTIF Pilot Building

3.1 Description of the energy system

CARTIF building is fully conditioned with a variety of different and complementary heating and cooling systems. It was designed under the concept as a living laboratory to test different internal and external loads in combination with several generation and distribution systems. The building has a complex energy system including renewable energy sources. The heating system is based on a solar thermal system and a gas-fired boiler to support the production of hot water for several purposes, domestic hot water, radiators, thermal active slabs and heat pumps in winter season and for operation of the absorption chiller in summer mode. The cooling facility has a water-water heat pump used to feed the fan coils and an evaporative cooling tower for condensing heat sink for the absorption chiller and the water-source heat pumps.

The building is completely monitored with one minute based frequency enabling the implementation of new strategies and management modes and the evaluation of every electrical and thermal facility installed. To analyse the precision of the regression method used it was chosen a complete year where the operating modes of the systems have a regular behaviour.

The energy demand systems to reach the indoor comfort level are based on different integrated technologies:

- Thermally activated slabs installed in the floor to provide heating and cooling services to each zone of the building. The control of this system is made by three ways valves managed by a thermostat in each zone.
- Water source heat pumps located in some laboratories to cover the peak of energy demand of the system. This system enables an independent regulation of each zone.
- Air heaters for conditioning of the industrial spaces of the building.
- Convective radiators installed in the north administrative area.

There are two operational modes, heating or cooling, of the overall system depending on the period of the year. For more details about the description of the systems, energy flow schemes and operation diagrams, see deliverables 5.1 and 6.1.

The regression models that have been developed for CARTIF pilot building focus on the two use cases proposed to be tested in order to optimize the behaviour of the Heating Ventilation and Air Conditioned (HVAC) systems: Use case 1 (Uc1) for winter time and Use case 2 (Uc2) for summer time.

3.2 IPMVP Specification

The previous document *“D6.3.1 Measure and Verification Plan”* defines the specifications of the methodology applied to evaluate the energy savings obtained by the implementation of BaaS solution as an Energy Conservation Measure (ECM). As it was mentioned in this document the evaluation of the energy savings is undertaken by the implementation of the International Protocol of Measure and Verification Plan (IPMVP). This protocol determines the energy savings comparing measured energy use before and after the implementation of an energy savings measure. The conditions affecting energy use of the building must be considered in the baseline and reporting periods with the same set of conditions in order to adjust the impact of this factor in the energy performance of the systems. The most common adjustment terms are weather conditions, occupancy and operating conditions of the building.

There are many other factors to be considered in the evaluation process of the energy savings, such as the building features, the available historical data related to the energy performance of the systems and the expected energy savings obtained. According to that, the IPMVP defines four different options to be adapted to the specific savings determination task.

In the case of CARTIF building, the evaluation process of the ECM implemented cannot be carried out in an isolated way with the installed energy meters. In addition, the energy savings that are expected with the implementation of BaaS solution are more than 10% and it is not necessary to assess each ECM separately. Therefore the IPMVP recommends analysing the data gathered by the main energy meters of the building, which is the "***Option C: Whole Facility***". In this option, all the data measured and gathered during the baseline period are processed and analysed in order to adjust and validate the model and after that, all the reference energy consumptions are calculated with the regression model. Once the BaaS solution is implemented in the Pilot Buildings, the reporting period can be started and therefore the energy savings can be evaluated.

Once has been selected the option of the IPMVP the next step is to define the measurement boundary of the energy systems of the building, taking into account the use case previously proposed. The measurement boundary is determined by the selection of the IPMVP Option.

3.3 Measurement boundary

The following table defines the conditions of the evaluation process for CARTIF building.

Building	Measurement Boundary
CARTIF Building	Gas consumption from gas supplier. Thermal energy consumption. Electricity consumption from electricity supplier.

Table 3: CARTIF Building measurement boundary

Energy meters use to evaluate energy savings in CARTIF Building are:

- G: Gas meter that measure energy consumption from gas supplier.
- H: Thermal energy meter.
- E: Electrical meter that measure energy consumption from electrical network.

Applying the IPMVP Option C, the measures from E, H and G meters are needed to develop the model.

3.4 Baseline Period

The baseline period should represent all operating modes of the building. The length of the baseline period should be such that it contains all situations of building energy consumption. Each building has a different use and could have a different baseline period, where all energy profiles can be.

CARTIF Building is an offices building that has heating and cooling systems and is located in Valladolid (Spain). Energy consumption mainly depends on the occupancy of the building and weather conditions. Taken into account the use cases that have been defined, the heating season should be the baseline period for the modelling of the use case 1 (winter) and the cooling season should be the baseline period for the use case 2 (summer).

Taking into account both parameters (occupancy and weather) and ECM implementation plan, selected baseline period of CARTIF Building is presented in the next table. It contains two heating seasons (November 2013 – March 2014 and November 2014 – February 2015) and two cooling periods (June 2013 – September 2013 and June 2014 – September 2014).

Start of baseline period	End of baseline period
1st October, 2013	28th February, 2015

Table 4: CARTIF Building baseline period

3.5 Independent Variables

The energy consumption in the pilot buildings mainly depends on external conditions (weather) and internal conditions (comfort, occupancy...).

CARTIF Building has two different energy schemes depending on the season: Winter Energy Scheme and Summer Energy Scheme. It is considered that the winter period is from November to March, while the summer period is from June to September.

The independent variables that are considered for CARTIF pilot building are the indoor temperature in the building, the outdoor temperature and the solar radiation. The weather data are gathered in the weather station located in CARTIF pilot building, and the indoor conditions are measured with different sensors installed in different rooms of the building.

Due to simplicity, at the end it was decided to use the outdoor temperature (daily average or average in the operation hours) instead of the heating degree days (HDD) in winter (Uc1) or cooling degree days (CDD) in summer (Uc2).

1st Variable	2nd Variable	3rd Variable
Indoor temperature	Outdoor temperature	Solar radiation

Table 5: CARTIF Building independent variables

It is important to remark that, despite the fact that it is initially considered that all of these variables have a clear influence on the problem under study, during the development of these studies (data processing, analysis and modelling) different issues can appear (lack or inconsistency of data, illogical results, etc.). This will lead, depending on the cases and the models, to include or not some of these variables or to particularize the models integrating specific corrections derived from the data exploration.

3.6 Static Factors

Static factors are those parameters that describe the installation and operation of the building and remain constant coinciding with baseline period, from energy consumption point of view. They include different types and some of the most important are the following ones:

- **Building characteristics** (size, type, insulation and building envelope elements such as walls, roofs, doors, windows): It is assumed that the building characteristics are the same during the whole baseline period.
- **Equipment inventory** (nameplate data, location, condition): The equipment is supposed to be the same, in terms of quantity and operation, during the baseline period
- **Occupancy** (type, density and periods): It has been considered that the occupancy of the building is constant during the working timetable (7-15h).

- **Operating conditions**: operating period and season, schedules and set points.

For more details, all static factors considered for CARTIF Building have been included in *Deliverable 6.1 Appendix C.*

3.7 Adjusted Baseline Energy for CARTIF Building Use Case 1: Winter

The winter use case proposed in CARTIF pilot building is the optimization of the energy performance of the heating system, trying to maximize the use of solar thermal generation in order to minimize the global energy consumption (natural gas, thermal and electrical consumption) associated to the heating system working on winter mode considering the user comfort constraints.

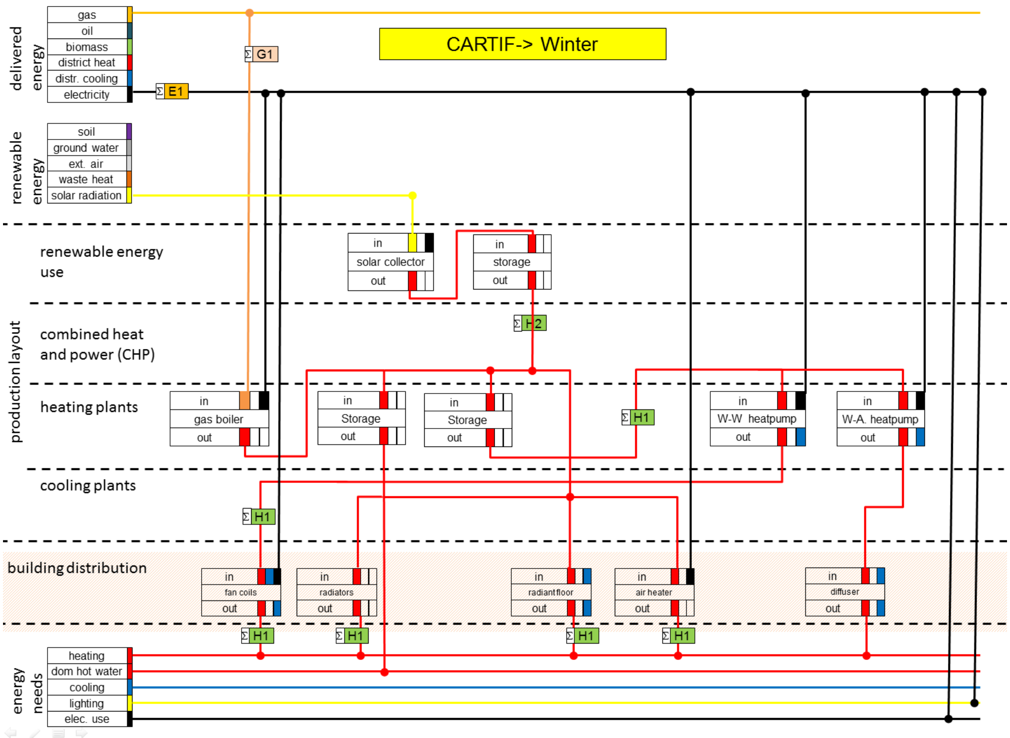

Figure 1: CARTIF Building Winter Energy Scheme

CARTIF building have a heating system with a gas boiler and solar panels connected through an inertial tank to the distribution system to provide energy to the thermal slabs and fancoils installed in the zones of the building. The renewable contribution from the solar panels to the heating system has priority but it depends on the radiation. The management system is in charge of the optimization of the energy performance of the facility. The operating strategy implemented for the management of the heating system use the gas boiler to maintain the indoor comfort conditions when the solar panels cannot cover the energy demand of the building.

The scheme of the heating system is represented in the following diagram.

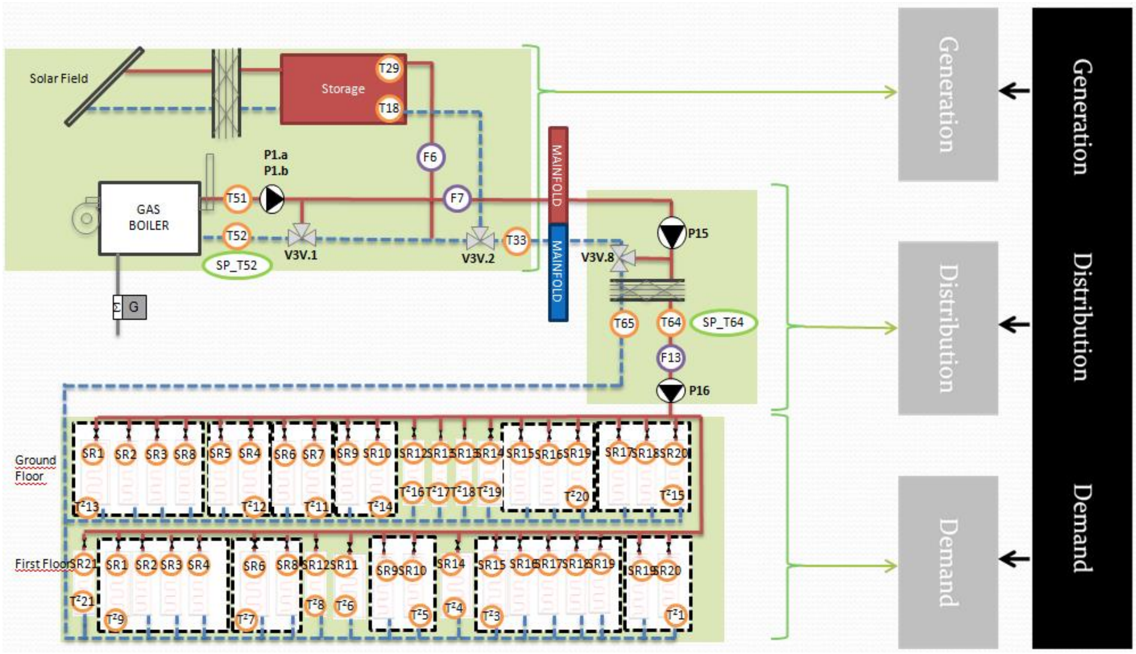

Figure 2: CARTIF Building Winter Use Case diagram scheme

In order to develop the regression analysis for the two use cases, the focus will be on the last winter (heating) periods respectively.

Start of baseline period	End of baseline period
1st November, 2013	28th February, 2014

Table 6: CARTIF Building baseline period for the Use Case 1

After a comprehensive previous study aimed to understand the characteristics and operation of the energy system for the winter user case in CARTIF pilot building, numerous regression analysis have been conducted trying to model the energy consumption during the winter period (focussing in the natural gas) referencing it to different independent variables such as external conditions (outdoor temperature and solar radiation) and indoor conditions (indoor temperature). These models are based on the baseline data of the pilot building. This analysis requires a previous work to gather, process and discriminate the data measured and collected by the different sensors and meters that are implemented in the pilot building, in order to adequate them for the regression analysis purpose.

The first approach is to look for a **linear regression model** for the gas consumption as a function of the outdoor temperature and solar radiation, due to its simplicity and the energy sense (easier to handle and interpret).

The regression analyses included in this section assume a **daily modelling** (each day represents a data point of the model) of the problem under study. In this modelling approach, those variables related to energies (gas, electricity, solar radiation...) should be included as the total daily consumption. On the other hand, other variables such as temperatures may be included as the average daily temperature. This consideration has been taken based on the evidence that a building heating system is a very inertial system: the response of the energy system is not instantaneous, that is, the gas consumption has not an immediate effect in the heating of the building, and thus in the increase of the indoor temperature. It takes a certain time to heat the rooms inside the building.

Taking into account the use case that has been proposed to optimize, two key have to be included in all the models: natural gas consumption and solar energy.

On the one hand, the **natural daily gas consumption** (in m^3) is taken as the response variable in all the regression models that will be considered. The gas meter does not measure the gas consumption directly, but it registers the gas accumulated, storing the data of the accumulated gas consumption every 1 minute. Therefore, the daily consumption is determined as the difference between the last and the first register of the day.

On the other hand, in order to characterize contribution of the solar energy to the heating of the building and to reduce the conventional energy consumption, the **solar radiation** received on the building will be considered as an input of the different models. Considering this variable, two factors are integrated in the analysis: directly, the solar radiation as an external component that only depends on the weather conditions, and indirectly, the solar thermal energy that can be generated which depends on the solar radiation received.

Finally, as it was previously mentioned, it should be numerous previous analyses were carried out in order to lead to the final models that are included in the following points of the present section.

Date	Day	G [m^3]	T_{ind} Vision 2D [°C]	T_{ind} Energías 2 [°C]	T_{ind} Energías 1 [°C]	T_{out} [°C]	Rad [kWh/m^2]
2	Sunday	11.55	18.22	18.52	18.24	-1.75	2.69
3	Monday	14.08	20.19	20.78	21.39	-2.17	1.57
4	Tuesday	8.75	20.42	20.16	20.71	1.29	1.55
5	Wednesday	8.97	20.47	20.89	21.39	2.67	2.21
6	Thursday	6.59	20.91	22.05	22.31	5.16	2.95
7	Friday	8.45	20.84	21.86	22.29	1.29	1.52
9	Sunday	9.61	18.94	17.84	18.35	0.09	0.81
10	Monday	12.92	20.16	21.33	21.74	1.29	3.79
11	Tuesday	8.56	20.32	21.35	21.94	-0.47	0.93
12	Wednesday	10.19	20.37	21.06	21.65	1.04	1.38
13	Thursday	6.51	20.92	22.09	22.29	6.00	2.11
14	Friday	5.78	21.27	23.29	23.10	7.56	3.74
16	Sunday	10.69	19.23	18.68	18.95	-1.65	2.19
17	Monday	14.14	20.30	21.97	22.48	0.99	4.51

18	Tuesday	8.44	20.52	22.01	22.26	0.82	1.54
19	Wednesday	9.53	20.35	22.39	22.29	2.13	4.87
20	Thursday	7.81	20.48	22.56	22.48	2.78	1.50
21	Friday	8.03	20.48	23.20	22.88	2.46	4.56
23	Sunday	8.20	18.66	19.57	19.27	2.88	5.00
24	Monday	10.79	20.51	21.37	21.35	1.60	2.11
25	Tuesday	8.02	20.74	22.03	22.21	2.48	2.84
26	Wednesday	9.57	20.14	22.84	22.76	2.17	4.29
27	Thursday	7.23	20.24	22.56	22.61	3.35	1.73
28	Friday	9.04	20.71	22.93	23.10	3.97	3.18

Table 7: Data summary of the modelling period

3.7.1 Model 1

Independent variables

As an initial approach, it is considered that the energy consumption should be represented as a function of the external conditions (outdoor temperature and solar radiation) and the indoor conditions (indoor temperature). According to that, the following variables will be included in the model as inputs or independents variables:

- **Indoor temperature** [°C]: Average daily indoor temperature. Considering the occupancy level and the orientation of CARTIF building, they have been selected three different thermal zones to obtain this indoor temperature: Vision 2D, Energias2 and Energias1. The data are taken from the registers (every 1 minute) of the temperature sensors (UBC5, UBC7 and UBC8) installed in the three zones. There are two rooms (Vision 2D and Energias), but three thermal zones (Vision 2D, Energias 2 and Energias 1).
- **Outdoor temperature** [°C]: Average daily outdoor temperature obtained from the data registered by the weather station every 1 minute.
- **Solar radiation** [kWh/m^2]: Total solar radiation incident on the CARTIF building, calculated as the sum of values of solar radiation registered by the weather station (W/m^2) every minute.

Modelling period

After a comprehensive study of the occupancy of the building in the winter period, the timetables and bank holidays, profile and ranges of the variables under study, etc. it has been concluded that **February** was the most representative and characteristic month for the modelling of the winter use case of the CARTIF Building.

Model 1	
Period	1^{st} February 2014 – 28^{th} February 2014
Frequency	Daily (a day corresponds to a point of the model)

Table 8: Modelling period and frequency

It should be taken into account that the value of the gas meter in all the Saturday does not change during the periods understudy, which means that the gas consumption on those days is zero. For this reasons, those points that correspond to Saturdays have been taken out of the model.

Model adjustment

The modelling strategy is to use multiple linear regression techniques to obtain a linear model that can predict the gas consumption as function of the indoor temperatures, the outdoor temperature and the solar radiation. This functional form (linear) is preferable due to its simplicity and the energy sense.

The coefficients obtained for the outdoor temperature and solar radiation should be negative; as they make that the gas consumption decreases. The sign of coefficients obtained for the indoor temperatures should be also negative: the higher is the daily average indoor temperature in the building, the lower is the energy needed to heat the building, so the lower is the gas volume consumed.

$$ABE_{WINTER} = a - b \cdot T_{ind}[^{\circ}C] - b \cdot T_{out}[^{\circ}C] - c \cdot Rad \;\; [kWh/m^2]$$

Equation 1: Adjusted Baseline Energy for the Uc1 of CARTIF pilot building

Analysis of the results and conclusions

Regression statistics	
Coefficient of determination R^2	64%
Adjusted R^2	58%
Standard error SE	1.42
Number of observations	24

Table 9: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	2.04	22.48	0.09	0.93
b (Slope for the	0.34	1.05	0.32	0.75

indoor temperature)				
c (Slope for the outdoor temperature)	-0.80	0.14	-5.72	0.00
d (Slope for the solar radiation)	0.57	0.24	2.36	0.03

Table 10: Summary of the variance analysis

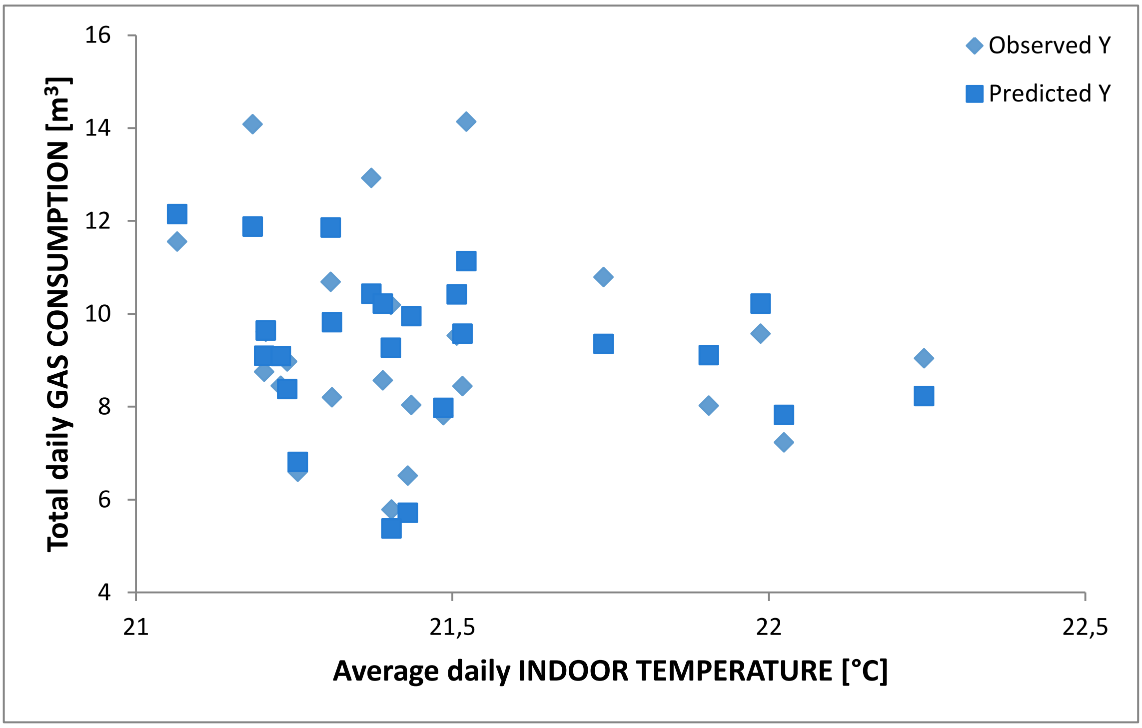

Figure 3: Adjusted regression curve with the indoor temperature

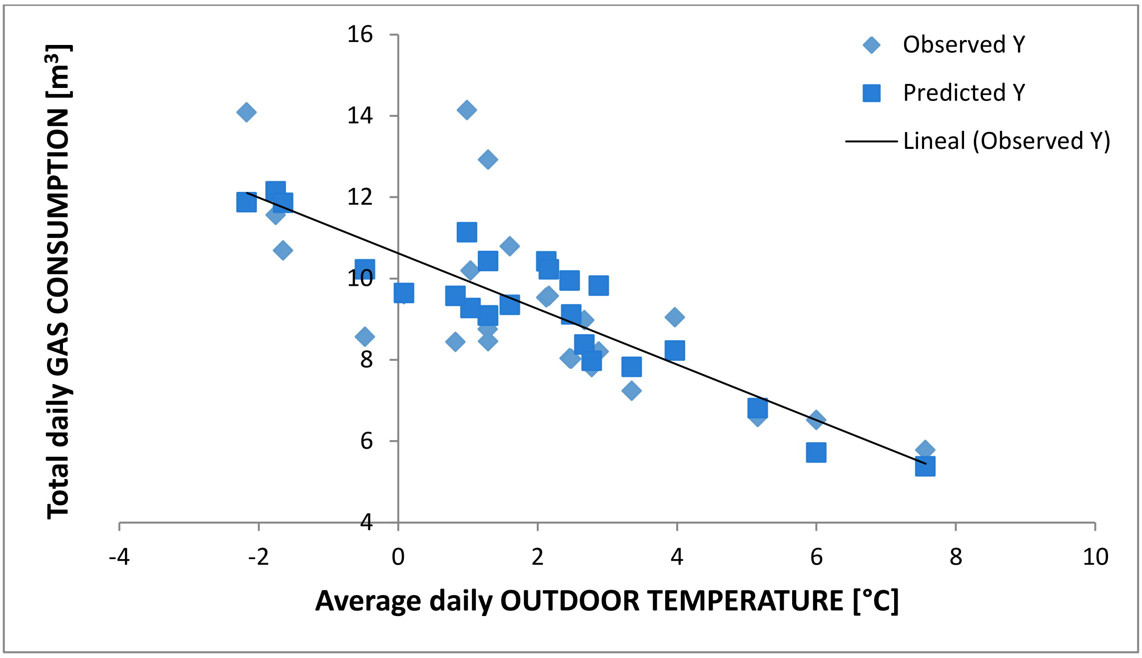

Figure 4: Adjusted regression curve with the outdoor temperature

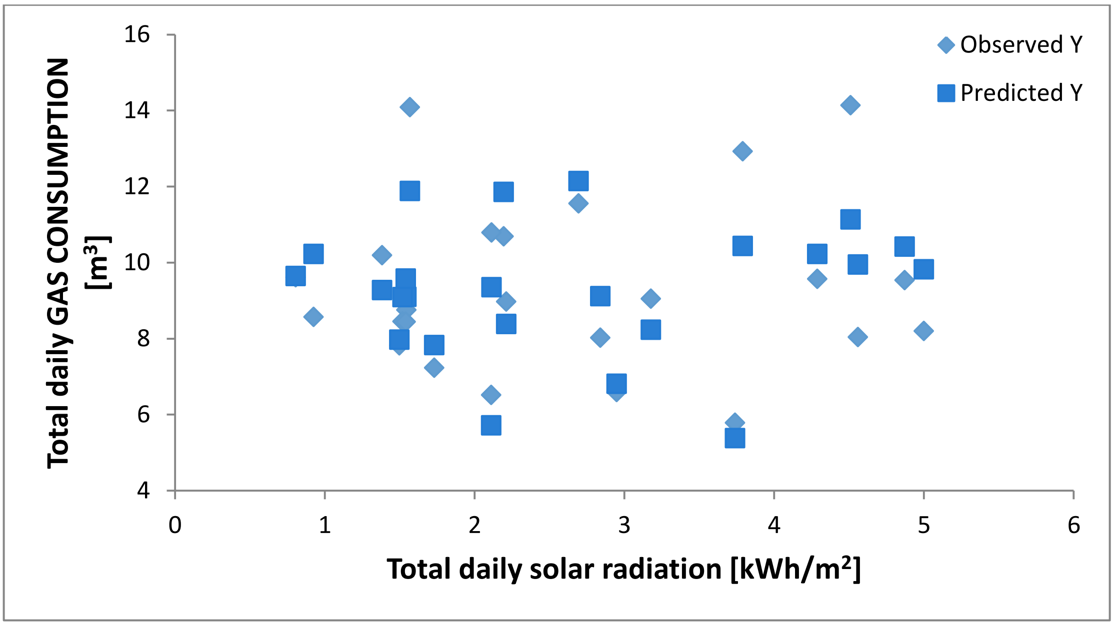

Figure 5: Adjusted regression curve with the solar radiation

The main conclusions of this regression analysis are the following ones:

- The slope of the solar radiation is positive (0.57) which means that the higher is the solar radiation, the higher is the gas consumption. This result is not consistent, because the solar energy contributes in the heating of the building and hence, it should reduce the gas consumption. This aspect is very important and suggests not using this model.
- R^2 (64%) is lower than the minimum acceptable level of 75% recommended by the methodology defined in the IPMVP.

- t-statistic is less than 2 for the indoor temperature coefficient, which means that this variables are not representative to explain the gas consumption with this model.
- p-value for coefficient b (related to the indoor temperature) is very high (0.75), which means that this variable is not representative at all in the model considered. Therefore, for further regression analysis this variable should not be included.

Taking into account all the previous considerations, the decision is to reject this regression model and to explore more the data in order to develop a better model.

The proposal for the next model is to study if any of the three most representative indoor temperatures in CARTIF Building, is a significant variable to study and represent the gas consumption. In order to do that, these indoor temperatures will be introduced in the regression model separately, as different independent variables, together with the outdoor temperature and the solar radiation.

Decision making	
Decision	**TO REJECT THE MODEL**
Change proposal	INCLUDE THE INDOOR TEMPERATURES IN THE MODEL BUT SEPARATELY

Table 11: Summary of the modelling decision making

3.7.2 Model 2

Independent variables

- **Indoor temperature in the room "Visión 2D" (UBC5)** [°C]: Average daily indoor temperature obtained from the data registered by the temperature sensor (UBC5) in the room "Visión 2D" every 1 minute.
- **Indoor temperature in the room "Energías 2" (UBC7)** [°C]: Average daily indoor temperature obtained from the data registered by the temperature sensor (UBC7) in the thermal zone "Energías 2" every 1 minute.
- **Indoor temperature in the room "Energías 1" (UBC8)** [°C: Average daily indoor temperature obtained from the data registered by the temperature sensor (UBC8) in the thermal zone "Energías 1" every 1 minute.
- **Outdoor temperature** [°C]: Average daily outdoor temperature obtained from the data registered by the weather station every 1 minute.
- **Solar radiation** [kWh/m^2]: Total solar radiation incident on the CARTIF building, calculated as the sum of values of solar radiation registered by the weather station (W/m^2) every minute.

Modelling period

As it has been described in the previous model, it has been concluded that the month of February 2014 is the most representative to study the winter use case in CARTIF building.

<u>Model adjustment</u>

The modelling strategy and the sign of the coefficients is the same than in the first model. The only difference is that the three indoor temperatures are included separately in the model.

$$G[m^3] = a - b \cdot T_{VISION\,2D}[^\circ C] - c \cdot T_{ENERGIAS\,2}[^\circ C] - d \cdot T_{ENERGIAS\,1}[^\circ C] - e \cdot T_{out}[^\circ C] - f \cdot Rad\,[kWh/m^2]$$

Equation 2: Adjusted Baseline Energy for the Uc1 of CARTIF pilot building

<u>Analysis of the results and conclusions</u>

Regression statistics	
Coefficient of determination R^2	74%
Adjusted R^2	67%
Standard error SE	1.27
Number of observations	24

Table 12: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	7.21	14.12	0.51	0.6156
b (Slope for the indoor temperature in Vision2D room)	-0.11	1.13	-0.09	0.9264
c (Slope for the indoor temperature in Energias2)	-2.79	1.26	-2.21	0.04051
d (Slope for the indoor temperature in Energias1)	2.91	1.49	1.96	0.0659
e (Slope for the outdoor temperature)	-0.74	0.18	-3.99	0.000854
f (Slope for the solar radiation)	0.90	0.28	3.25	0.004455

Table 13: Summary of the variance analysis

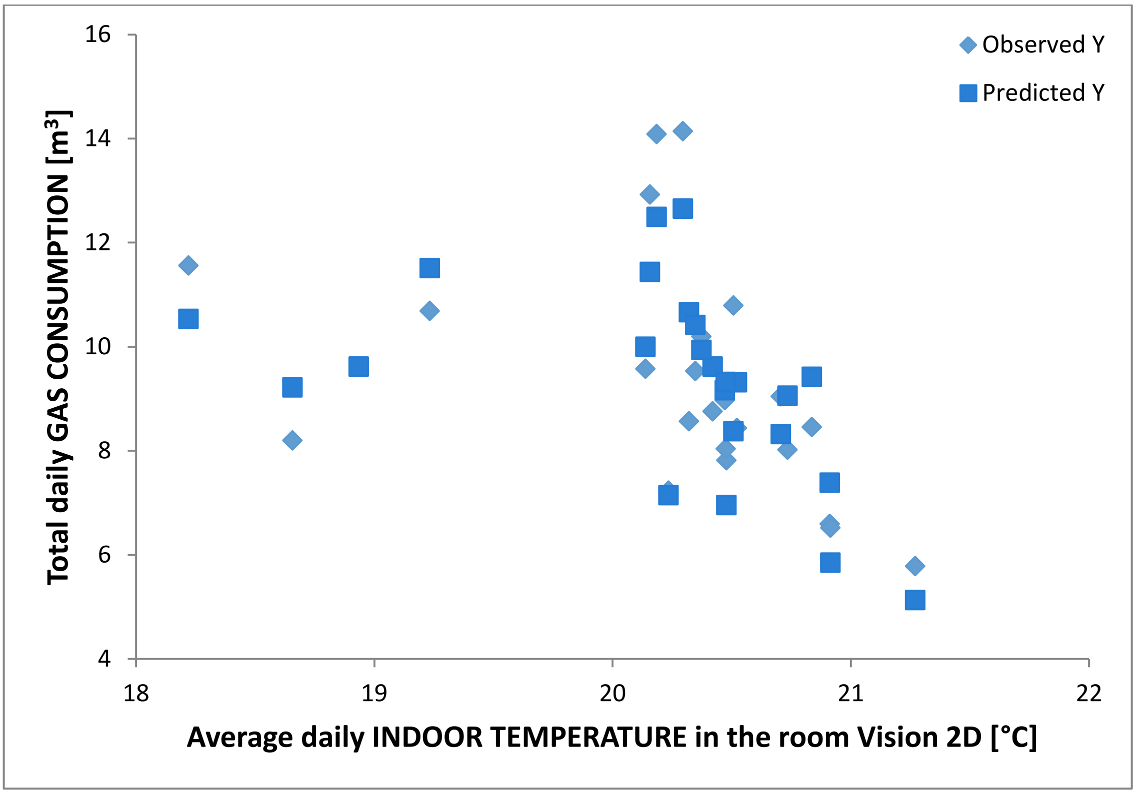

Figure 6: Adjusted regression curve with the indoor temperature in Vision 2D room

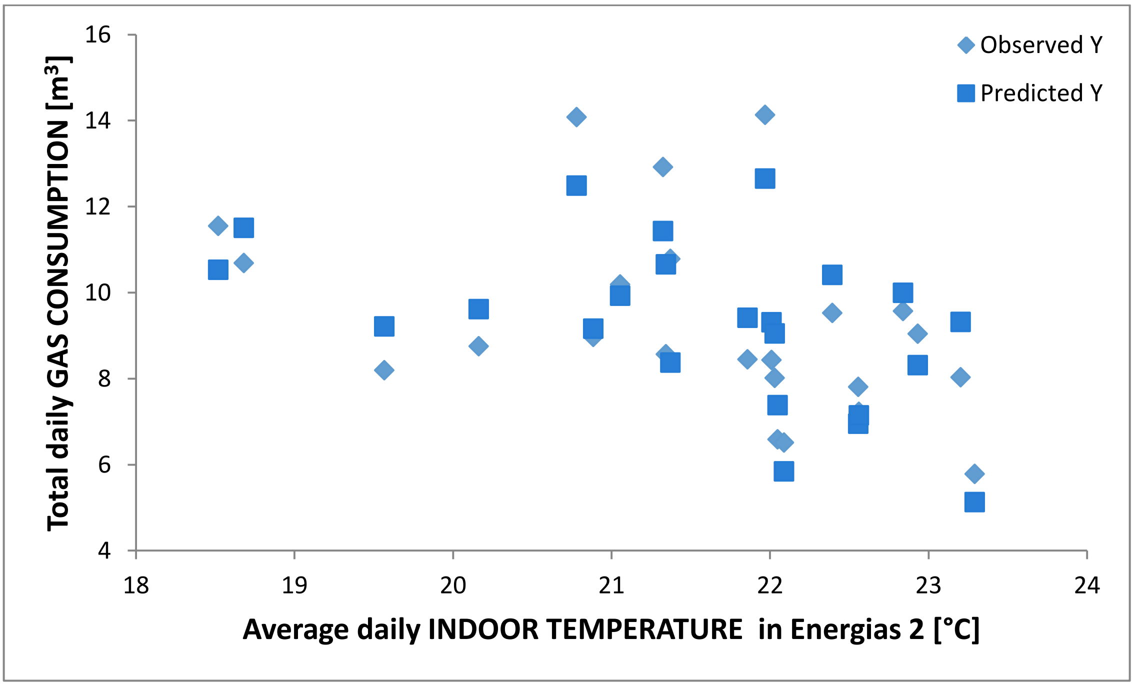

Figure 7: Adjusted regression curve with the indoor temperature in Energias 2

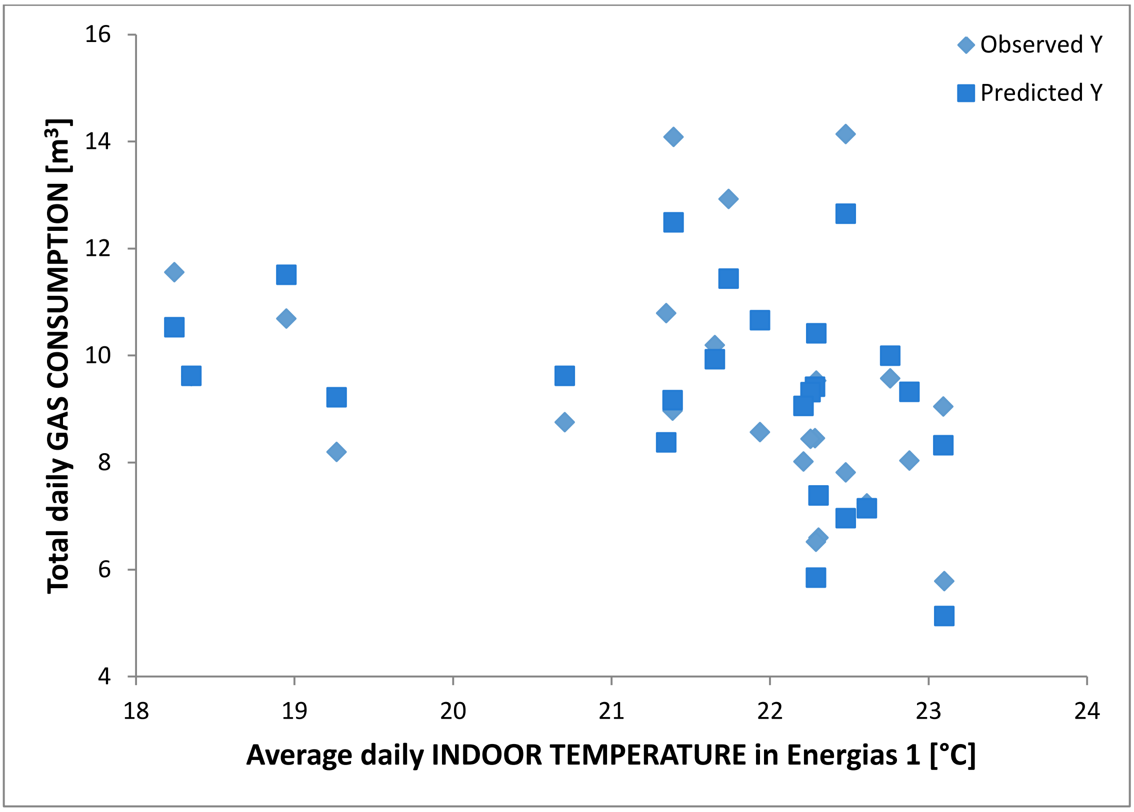

Figure 8: Adjusted regression curve with the indoor temperature in Energias 1

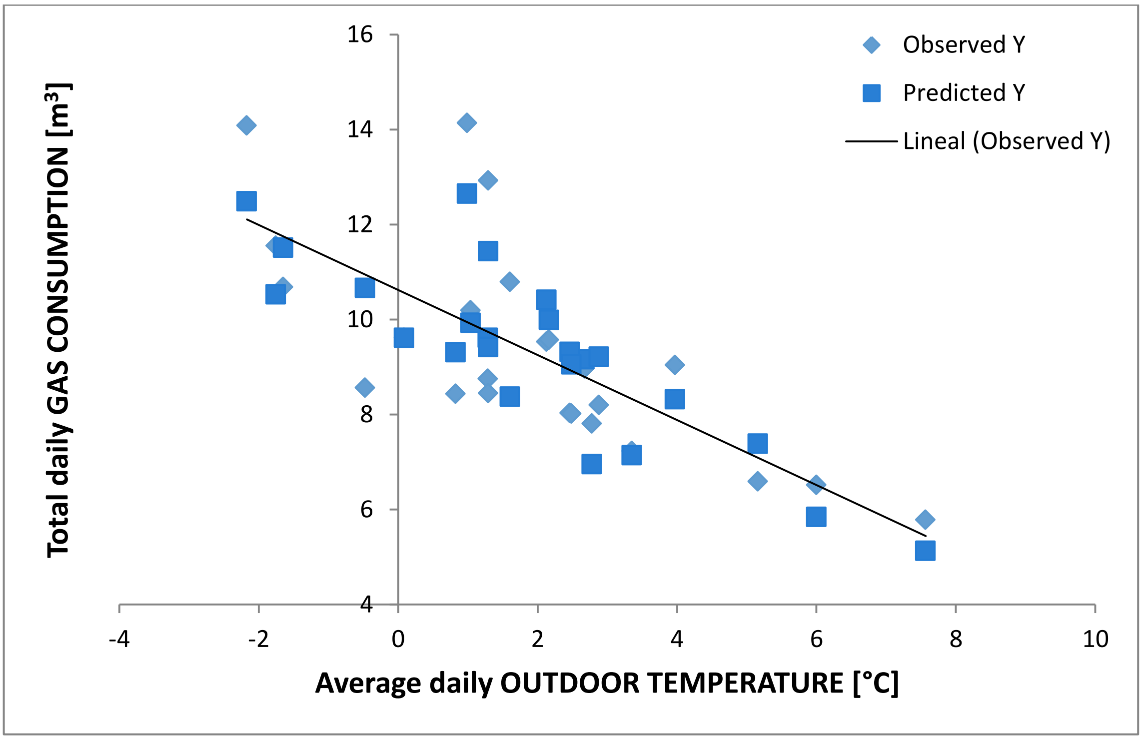

Figure 9: Adjusted regression curve with the outdoor temperature

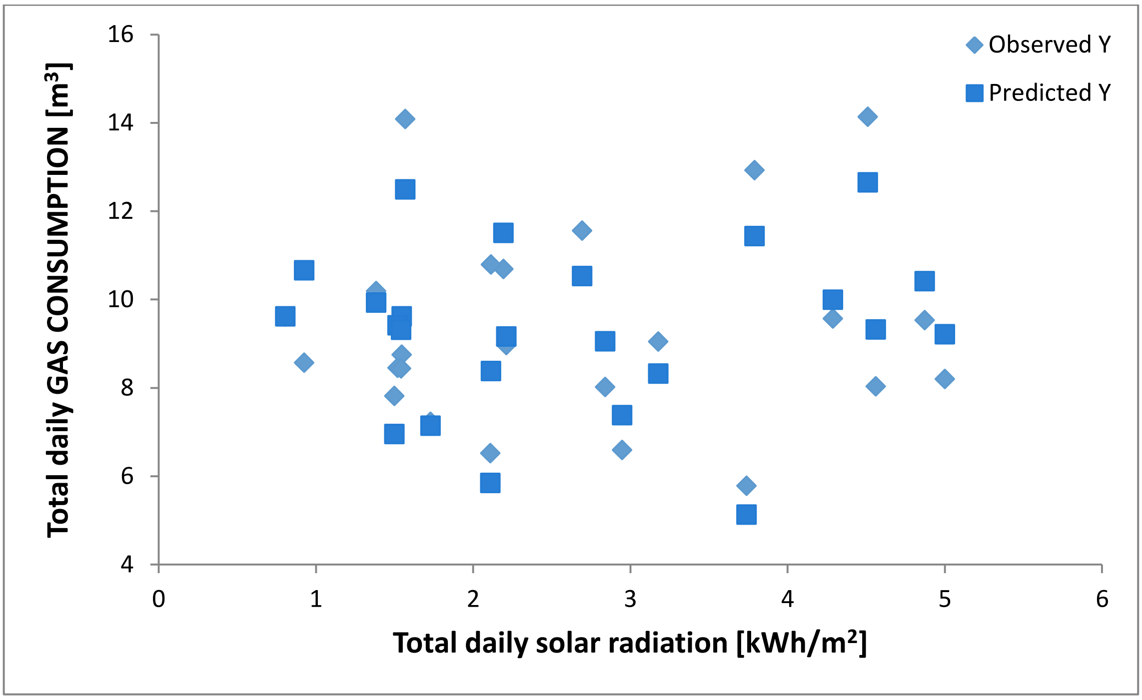

Figure 10: Adjusted regression curve with the solar radiation

The main conclusions of this regression analysis are the following ones:

- The slope of the solar radiation is positive (0.90) which would mean that the higher is the solar radiation, the higher is the gas consumption. This result is not logical, because the solar energy contributes in the heating of the building and, therefore, it should reduce the gas consumption. This aspect is very important and suggests not using this model, as it is against the initial hypothesis.
- R^2 almost reach the minimum acceptable level of 75% recommended by the methodology defined in the IPMVP.
- t-statistic is less than 2 for some coefficients, which means that those variables are not representative to explain the gas consumption.
- p-value for coefficient b (related to the indoor temperature in Vision 2D room) is extremely high (0.93), which means that this variable is not representative at all in the model considered. Therefore, for further regression analysis this variable should not be included. A similar situation occurs with the other two indoor temperatures (Energias2 and Energias1), as they present a p-value a bit high (0.040 and 0.065 respectively) that may indicate that these two variables are not very significant to represent the gas consumption, and therefore they should not be included in the model.

According to the above, this model cannot be considered as valid, and it would be rejected.

As an intermediate step, another analysis has been carried out removing the less significant indoor temperature, which is “Indoor temperature in the room Vision2D”. The regression results shows a similar value of R^2 (74%) and better results in terms of adjusted R^2 (68%), SE (1.23) and t-statistic (higher than 2 for all the slopes, in absolute value). However, the estimated coefficient for the solar radiation is still positive, and hence this model cannot be considered as adequate. In addition, the results again show that the indoor temperatures that have been included (Energías2 and Energías1) have p-values that are a bit high (0.021 and 0.014, respectively), compared to the ones for the weather conditions. Thus, this model has to be rejected again.

Therefore, in following analyses the indoor temperatures will not be included in the gas consumption model. The proposal for the next model is to not include the indoor temperatures in the model and to study the gas consumption only depending on the outdoor temperature and the solar radiation.

Decision making	
Decision	**TO REJECT THE MODEL**
Change proposal	NOT TO INCLUDE THE INDOOR TEMPERATURES IN THE MODEL AND TO STUDY ONLY THE EXTERNAL CONDITIONS

Table 14: Summary of the modelling decision making

3.7.3 Model 3

Independent variables

According to the conclusions drawn in the previous model, only the external conditions will be considered to try to explain the gas consumption in the CARTIF pilot building. To that end, the outdoor temperature and the solar radiation are the variables that have a higher influence on the energy consumption and therefore their impact is easier to understand and explain in the energy modelling:

- **Outdoor temperature** [°C]: Average daily outdoor temperature obtained from the data registered by the weather station every 1 minute.
- **Solar radiation** [kWh/m^2]: Total daily solar radiation incident on the CARTIF building, calculated as the sum of values of solar radiation registered by the weather station (W/m^2) every minute.

Modelling period

As it has been described in the previous model, it has been concluded that the month of February 2014 is the most representative to study the winter use case in CARTIF building. The data points used for this model for the gas consumption, outdoor temperature and solar radiation are the same than in the previous one.

Model adjustment

$$G[m^3] = a - b \cdot T_{out}[^\circ C] - c \cdot Rad_{previous}\ [kWh/m^2]$$

Equation 3: Adjusted Baseline Energy for the Uc1 of CARTIF pilot building

Analysis of the results and conclusions

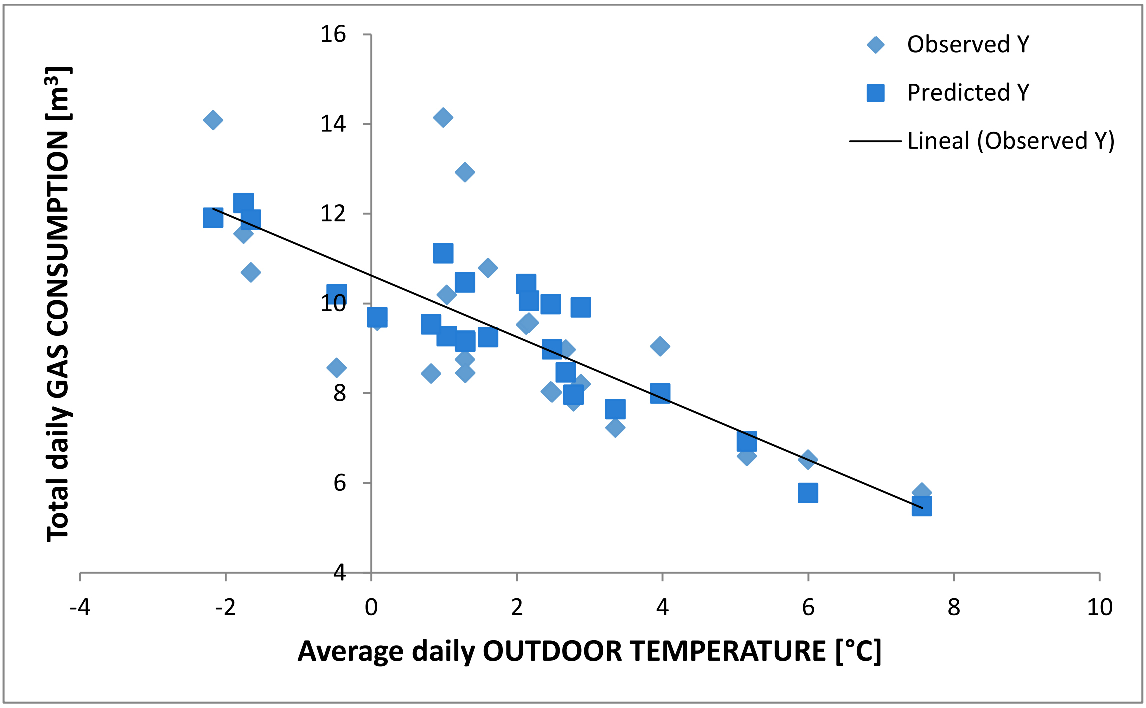

Figure 11: Adjusted regression curve with the outdoor temperature

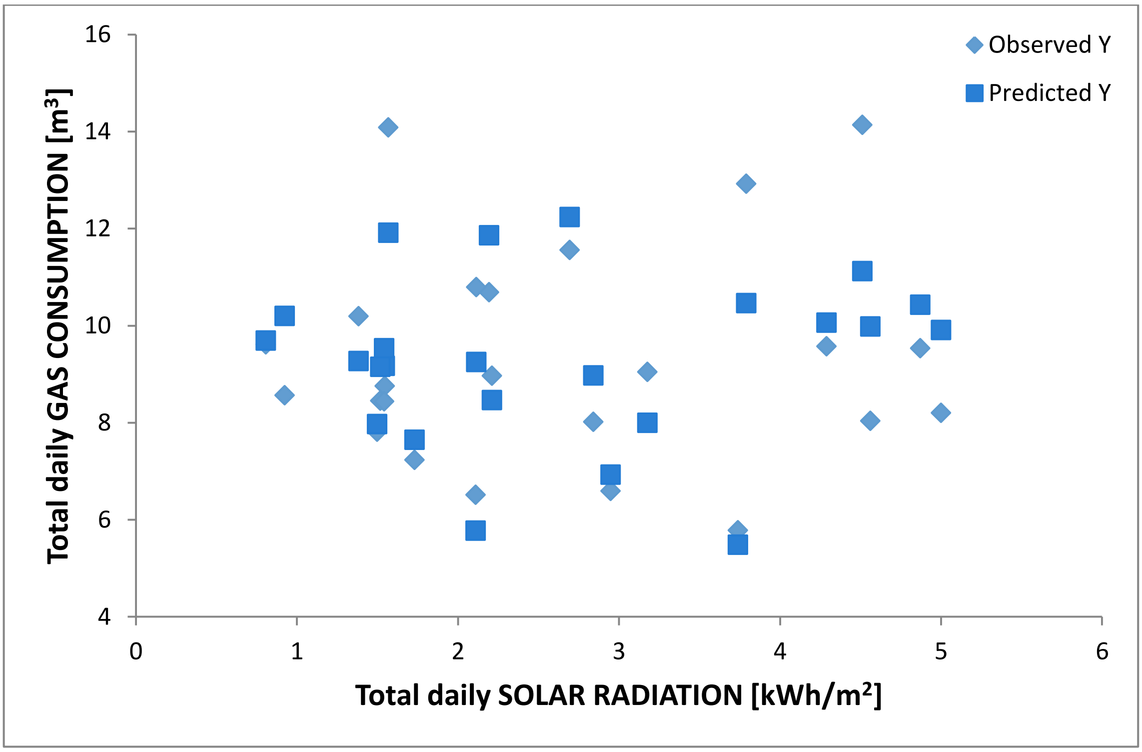

Figure 12: Adjusted regression curve with the solar radiation

Regression statistics	
Coefficient of determination R^2	63%
Adjusted R^2	60%
Standard error SE	1.39
Number of observations	24

Table 15: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	9.29	0.65	14.20	0.00
b (Slope for the outdoor temperature)	-0.79	0.13	-6.00	0.00
c (Slope for the solar radiation)	0.58	0.23	2.47	0.02

Table 16: Summary of the variance analysis

The main conclusions that can be drawn for this regression analysis are the listed below:

- The value that has been obtained for the solar radiation coefficient is positive which has no energy sense as the gas consumption should be lower when there is more solar radiation, as less energy is needed to heat the building and increase the indoor temperature and the comfort level. This leads to reject the model, as it is against the initial hypothesis.
- The value of R^2 (63%) does not reach the minimum acceptable level of 75% recommended by the methodology defined in the IPMVP. This leads to reject the model.
- The SE for the two slopes is not very high (0.13 and 0.23).
- The t-statistic takes a good value for the outdoor temperature and an acceptable one for the solar radiation.
- All the p-values are near zero, and therefore both variables are significant to model the gas consumption.

According to all the above conclusions, the decision is to reject this model and try to adjust a better one.

The proposal for the next model has to main points of actuation. First of all, to study the profile and period when there is gas consumption in the building and compare it with the period when there is solar radiation (sunshine hours), in order to understand the timetables and the influence of the solar energy in the consumption. Secondly, it is typical that in this kind of installation (e.g. offices building) the energy consumption on Mondays have a different profile and behaviour than all other days. This fact should be studied and considered in the modelling because it may have a high influence in the gas consumption and can be the reason of the bad results obtained in the previous regression analysis...

Decision making	
Decision	**TO REJECT THE MODEL**
Change proposal	TO STUDY THE PROFILES AND PERIODS WHEN THERE IS GAS CONSUMPTION AND SOLAR RADIATION TO STUDY IF THERE IS A DIFFERENT PROFILE OF CONSUMPTION ON MONDAYS

Table 17: Summary of the modelling decision making

3.7.4 CARTIF ABE_Uc1 Final Model

Independent variables

- **Outdoor temperature** [°C]: Average daily outdoor temperature obtained from the data registered by the weather station every 1 minute.
- **Solar radiation** [kWh/m^2]: Total daily solar radiation incident on the CARTIF building during the ***previous day***, calculated as the sum of values of solar radiation registered by the weather station (W/m^2) every minute.

Modelling period

In this model, the same period has been considered (**February** 2014).

Model adjustment

After a further exploration of the data, it has been observed that the gas consumption schedule is almost decoupled from the hours of sunshine, being zero during the hours when the solar radiation is significant. The fact is a key factor in the modelling of the energy consumption (in this case natural gas) and it implies that the solar radiation that the building receives one day influences more in the gas consumption of the next day. This thermal energy is stored in the inertia tanks and then it can be used to meet the future energy needs. For this reason, the contribution of the solar energy in the gas consumption should be included in the model as **solar radiation received the previous day.**

Exploring the data more deeply, it can be observed that the gas consumption on **Mondays** is higher than on all other days. This difference has a big impact in the consumption profile and, therefore, it is important to include this distinguishing factor as a correction in the regression analysis. This can be easily integrated in the model with a qualitative variable that takes on the value 1 when the day that is considered is Monday and 0 in all other cases. Therefore, the same gas consumption model can be adjusted for all the days. The regression curve will have the same slopes for the outdoor temperature and solar radiation for all the days, changing only the intercept on the case that it is Monday, which can be considered as a constant or correction factor.

The next equation represents the mathematical model for the gas consumption, as a function of the outdoor temperature and the solar radiation received by the building during the previous day. As it has been explained before, the coefficients for the independent variables (b and c) are the same for all the days, but the intercept (a) changes depending on if it is Monday or not.

$$G[m^3] = a - b \cdot T_{out}[^oC] - c \cdot Rad_{previous}\ [kWh/m^2]$$

Equation 4: Adjusted Baseline Energy for the Uc1 of CARTIF pilot building

Analysis of the results and conclusions

Regression statistics	
Coefficient of determination R^2	91%
Adjusted R^2	90%
Standard error SE	0.69
Number of observations	24

Table 18: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	10.82	0.37	28.98	0.00
b (Slope for the outdoor temperature)	-0.54	0.06	-8.41	0.00
c (Slope for the solar radiation)	-0.42	0.12	-3.53	0.00
d (Slope for the day/Monday correction)	3.53	0.39	8.99	0.00

Table 19: Summary of the variance analysis

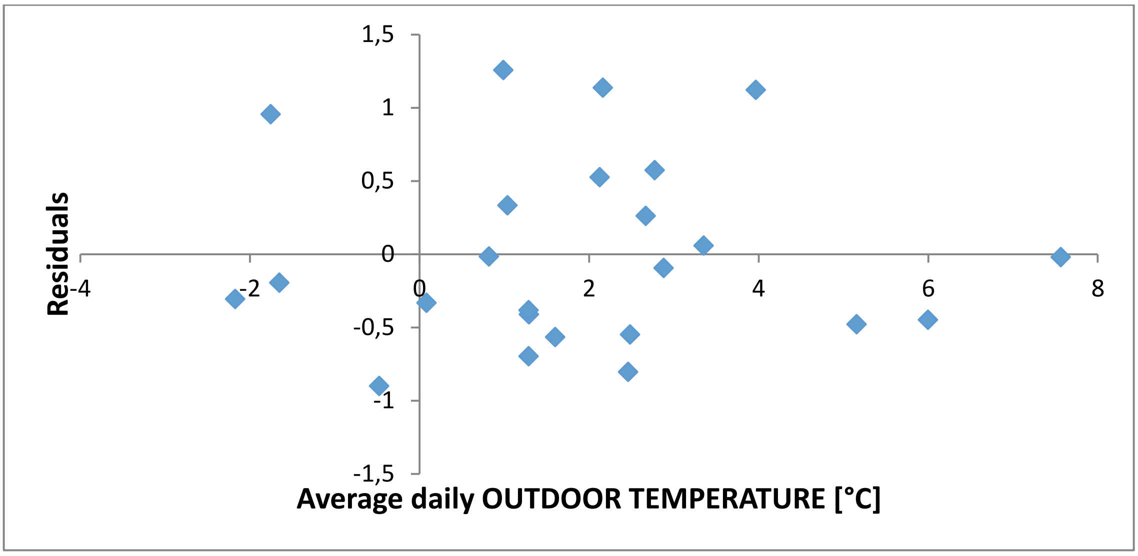

Figure 13: Residuals for the outdoor temperature

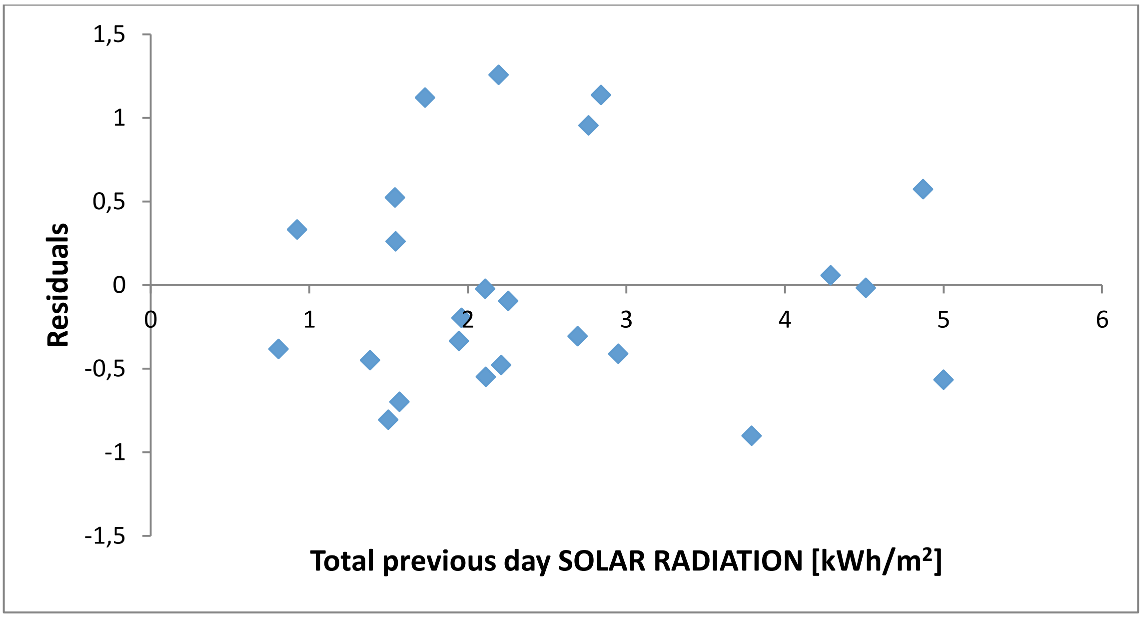

Figure 14: Residuals for the solar radiation

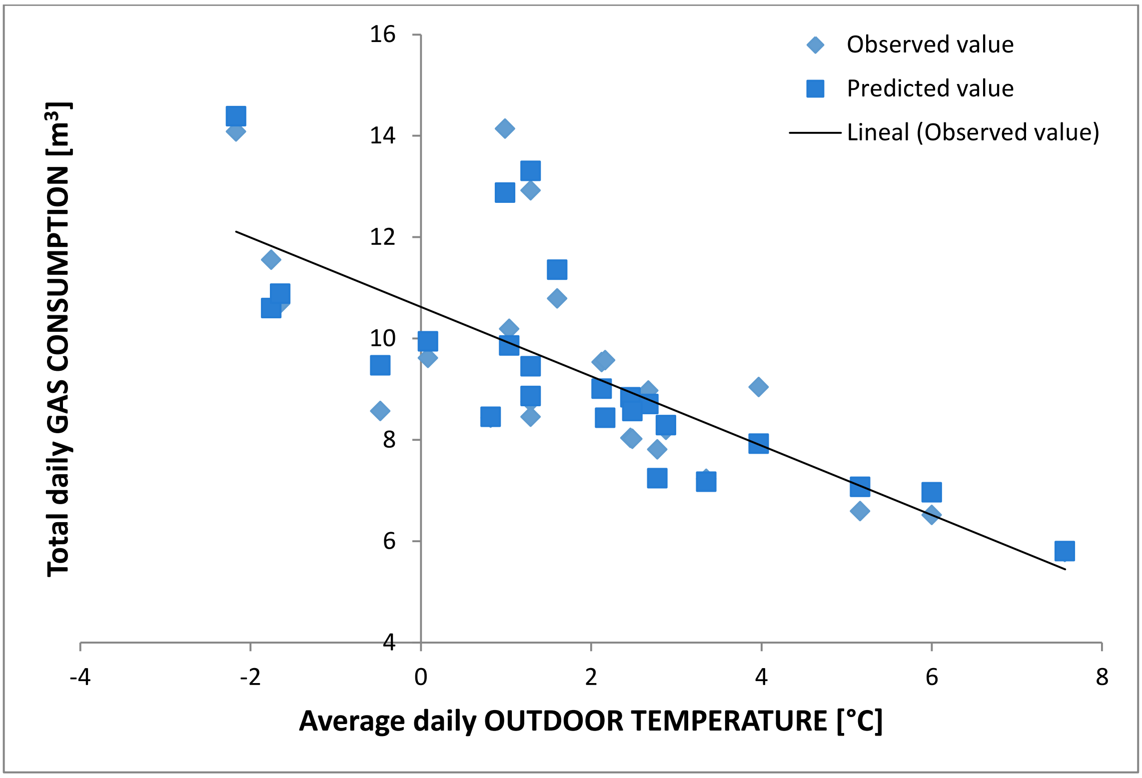

Figure 15: Adjusted regression curve with the outdoor temperature

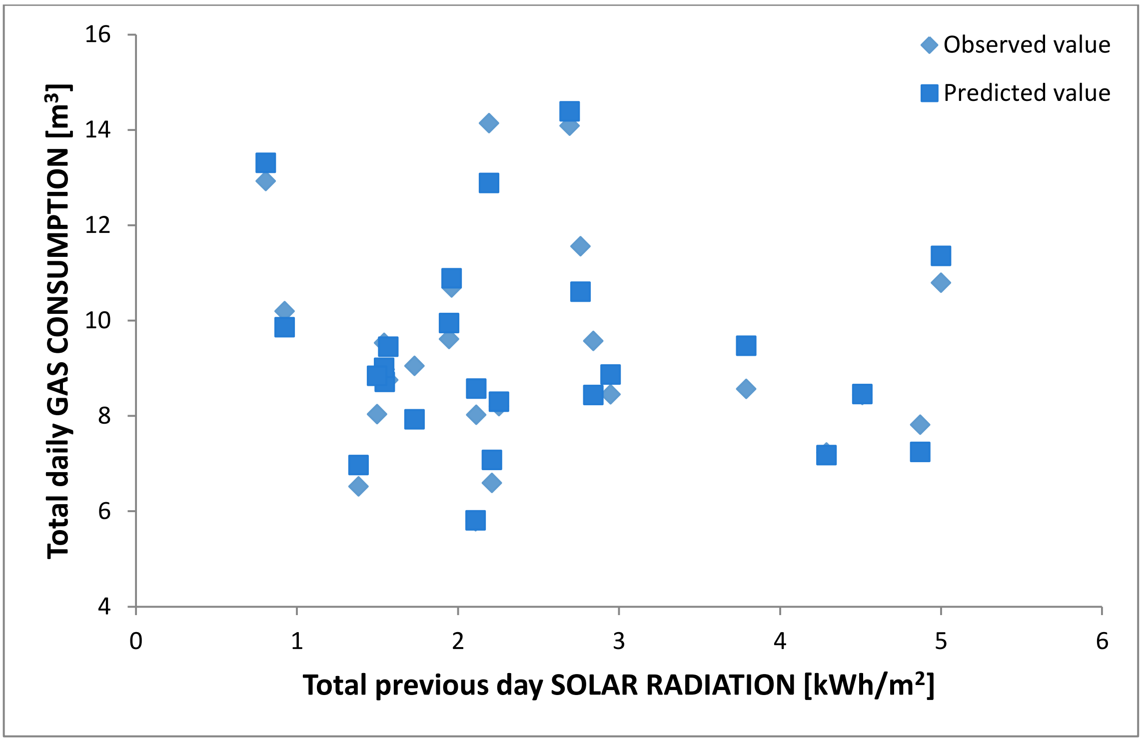

Figure 16: Adjusted regression curve with the solar radiation

The main conclusions that can be drawn from the regression analysis are the following ones:

- The obtained model combines two very important characteristics for energy modelling and regression analysis. First of all, its simplicity, in terms of functional form (linear) and number of independent variables (it only depends on two external conditions, including the Monday correction). Secondly, its accuracy, as the analysis of the statistic parameters shows that the model represents the problem under study very well.
- In addition, in this case the sign of the coefficient for the solar radiation is finally negative (also the one for the outdoor temperature), which means that the model is consistent from an energy consumption point of view. This aspect is essential to support the validity of the obtained model, together with the checking of the statistic tests.
- The R^2 obtained in this regression analysis is 91%, which means that the model explain almost all the variability of the gas consumption with the outdoor temperature and the solar radiation. This value is more than acceptable, as it far overcomes the minimum level recommended by the IPMVP methodology is 75%.
- The SE are low, t-statistic are greater than 2 for all the estimations in absolute value and p-values are almost null for all the independent variables (outdoor temperature, solar radiation and Monday correction), which mean that all this variables are significant for the explanation of the gas consumption.

On the basis of the above, this model can be accepted and will be considered as the valid and the definitive one.

Decision making	
Decision	**TO ACCEPT THE MODEL AND CONSIDER IT AS VALID TO APPLY THE IPMVP FOR CARTIF UC1**

Table 20: Summary of the modelling decision making

The next equations represent the ABE for the Uc1 in CARTIF pilot buildings and will be used to evaluate the energy savings achieved, following the IPMVP guidelines.

$$G = 10.82 - 0.54 \cdot T_{out} - 0.42 \cdot Rad_{previous}$$

Equation 5: CARTIF Building: Adjusted Baseline Energy for Uc1 (for normal days)

$$G = 14.35 - 0.54 \cdot T_{out} - 0.42 \cdot Rad_{previous}$$

Equation 6: CARTIF Building: Adjusted Baseline Energy for Uc1 (for Mondays)

In a nutshell, a model to estimate the natural gas consumption (total daily) as a linear function of the outdoor temperature (daily average) and solar radiation (total previous day) has been developed, obtaining an accurate adjustment to the considered data points of the baseline period. In order to consider the distinctive feature consisting that on Mondays the heating consumption is higher than the rest of the days, only a correction on the intercept of the model has been included: the coefficient 14.35 is the sum of the intercept for normal days (10.82) and the correction for Monday’s extra-consumption (3.53). The coefficients of the outdoor temperature and the solar radiation are the same for all the days.

3.8 Adjusted Baseline Energy for CARTIF Building Use Case 2: Summer

Summer operating mode in CARTIF building is based on heat pumps supplied by the cooling tower. The next figure represents the energy flow scheme of the metering system for the CARTIF pilot building including energy sources, distribution systems and different energy subsystems suppliers to maintain required indoor conditions.

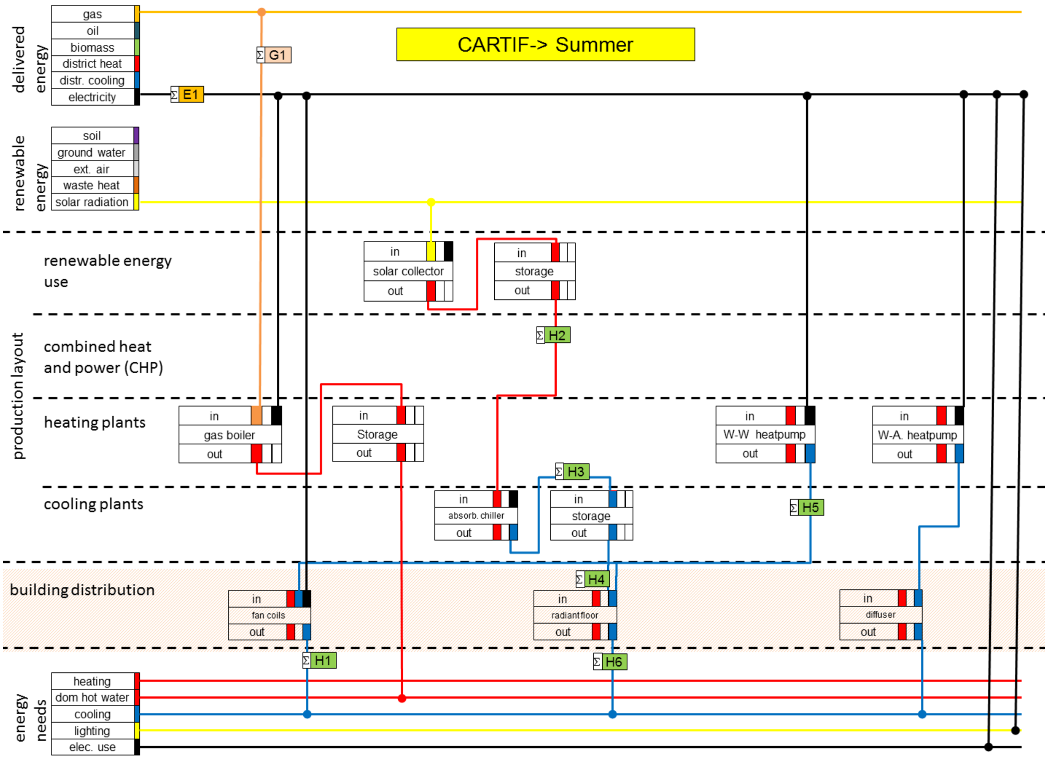

Figure 17: CARTIF Building Summer energy flow scheme

CARTIF building has a cooling system based on a conventional chiller and an absorption chiller connected with the solar thermal installation. The generation system provides energy through a distribution system to some water heat pumps that supply thermal energy for fancoils installed in the zones of the building. The thermal energy is generated by renewable energy sources and mechanical compression, but taking into account that the operation of the absorption chiller is manually managed and the use of this system is limited, the proposed summer use case is focused on the optimization of the mechanical cooling system.

The conventional mechanical cooling chiller is managed by schedule and the demanded energy is controlled by the return temperature of the installation. The water source heat pumps are installed in each zone to provide cooling to thermal comfort conditions. The flow temperature of the cooling tower is regulated by the temperature set point according to the schedule defined by the maintenance staff.

As represented in the functional scheme of the next picture, there are three subsystems considered in summer operating mode, generation, distribution and demand.

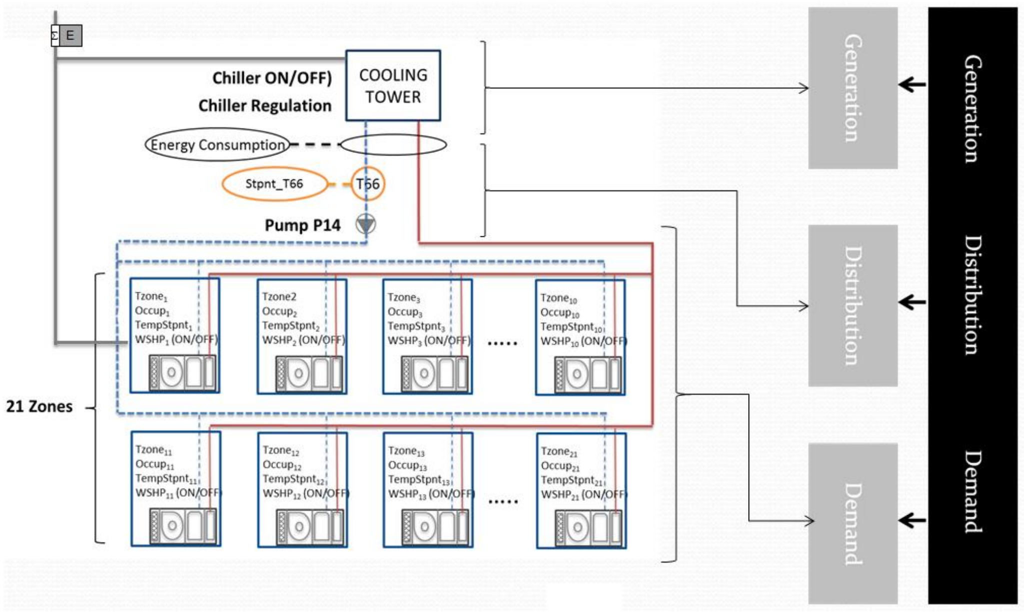

Figure 18: CARTIF Building Summer Use Case diagram scheme

In order to deploy the regression analysis for the use case proposed, the evaluation time has been focus on the last summer period. The reference period established for the evaluation of the regression model in the summer use case proposed in CARTIF building has been measured and monitored before the ECM is implemented as reflected in the next table.

Start of baseline period	End of baseline period
1st June, 2014	30th September, 2014

Table 21: CARTIF Building baseline period for the Use Case 2

The main objectives of the evaluation procedure carried out are to provide information about the energy performance of the building, the indoor thermal comfort and the efficiency of the cooling systems in order to define the baseline period as a reference for the future expected energy performance improvements in summer period. The deployment of the regression model will enable to demonstrate the impact of the BaaS solution as energy efficiency measure keeping the comfort conditions in the summer case proposed.

After a further analysis and understanding of the operation and features of the cooling energy system in CARTIF pilot building, several regression analysis have been conducted in order to validate the regression model. The output or dependent variable in all of these analyses has been the energy consumption of the cooling system in the summer period. Outdoor temperature, indoor temperature, solar radiation, etc. have been taken as inputs or independent variables.

The data analysis requires a previous work to process all the historical data gathered by different devices implemented in the pilot building because there are a lot of variables with different characteristics (rate, period, frequency, etc). The historical data of CARTIF pilot building have been collected with different frequencies between 1 to 5 minutes. For these reasons, this previous processing work is necessary to adequate the required parameters for the regression analysis purpose. This process involved a lot of resources taking into account the amount of data recorded for the Building Management System (BMS) of CARTIF building with different frequencies and some failures in data collection. The BMS installed manages the mechanical and electric systems and the indoor conditions allowing to record measurement parameters as a data acquisition system but the management of historical data need to be carried out manually in order to obtain the required variables for the regression model.

This document describes the methodology deployed including also the unsuccessful evaluations and reporting of results. The process includes all the previous analyses with the valuable conclusions obtained from each one, the indicators to be used, the methods, frequency, measurement conditions and statistical adjustment issues.

The regression analyses included in this section assume a daily frequency modelling for the variables involve in the process. The total daily consumption is used as dependent variable and the average daily values for temperatures, radiation, etc are treated as independent variables.

These premises are based on the conclusion of the analysis of the historical data that reflect that the building has proper insulation and for this reason the inertia of the building have a big influence on the response of the energy system. These conclusions are reflected in the analysis carried out in order to consider external weather conditions as independent variables in the assessment of the regression model. Therefore, outdoor temperature has been included as an input in the evaluation procedure of the different models.

In the following points are included a summary of the most representative analyses performed in the summer use case for CARTIF building in order to find an accurate regression model.

Date	Day	Outdoor Temperature [ºC]	Indoor Temperature [ºC]	Radiation [W/m2]	Power [W]
01/08/2014	Friday	20.72	25.61	693.04	551,200
04/08/2014	Monday	20.28	25.52	666.09	539,500
05/08/2014	Tuesday	20.12	25.54	697.46	418,100
06/08/2014	Wednesday	19.62	25.61	699.69	438,100
07/08/2014	Thursday	21.74	25.73	690.84	436,000
08/08/2014	Friday	20.76	25.88	651.04	614,300
11/08/2014	Monday	20.76	25.88	651.04	564,800
12/08/2014	Tuesday	18.34	25.89	623.22	564,800
13/08/2014	Wednesday	17.13	25.90	712.65	465,900
14/08/2014	Thursday	16.91	25.61	707.23	346,100
15/08/2014	Friday	17.58	25.31	696.62	206,300
18/08/2014	Monday	22.44	25.33	602.75	325,000

19/08/2014	Tuesday	19.28	25.51	679.25	516,100
20/08/2014	Wednesday	18.00	25.08	686.91	365,900
21/08/2014	Thursday	17.78	25.32	620.38	424,900
22/08/2014	Friday	16.82	24.95	223.92	405,200
25/08/2014	Monday	19.78	25.46	680.73	385,100
26/08/2014	Tuesday	20.88	25.54	623.84	405,600
27/08/2014	Wednesday	21.19	25.65	628.86	438,100
28/08/2014	Thursday	20.22	25.42	676.72	444,300
29/08/2014	Friday	20.87	25.28	658.64	435,300

Table 22: Summer historical data

3.8.1 Model 1

Independent variables

The initial approach of this evaluation was considered that the energy consumption is represented as a function of the weather external conditions. According to this consideration, the outdoor temperature was included in the model as independent variable:

- **Outdoor temperature** [°C]: Average daily outdoor temperature collected minutely from the data registered by the weather station installed in the building.

Modelling period

The modelling period that has been considered is the month of August 2014, as it is the most representative of the summer season according to the climate conditions in Valladolid.

Model 1	
Period	1st August 2014 – 31st August 2014
Frequency	Daily

Table 23: Modelling period and frequency

Model adjustment

The modelling strategy used multiple linear regression techniques to obtain a linear model that reflect the thermal energy consumption as function of the outdoor temperature.

This linear regression form is preferable due its easy implementation and understanding of the energy sense of the model. The coefficient obtained for the outdoor temperature should be positive because the higher is the outdoor temperature the greater is the thermal energy needed to cool the building.

$$ABE_{SUMMER} = a + b \cdot T_{out} [^{o} C]$$

Equation 7: Adjusted Baseline Energy for the Uc2 of CARTIF pilot building

<u>Analysis of the results and conclusions</u>

Regression statistics	
Coefficient of determination R^2	7%
Adjusted R^2	2%
Standard error SE	93,314
Number of observations	21

Table 24: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	14,4180	24,4734	0.58	0.56
b (Outdoor temperature)	15,229	12,454	1.22	0.23

Table 25: Summary of the variance analysis

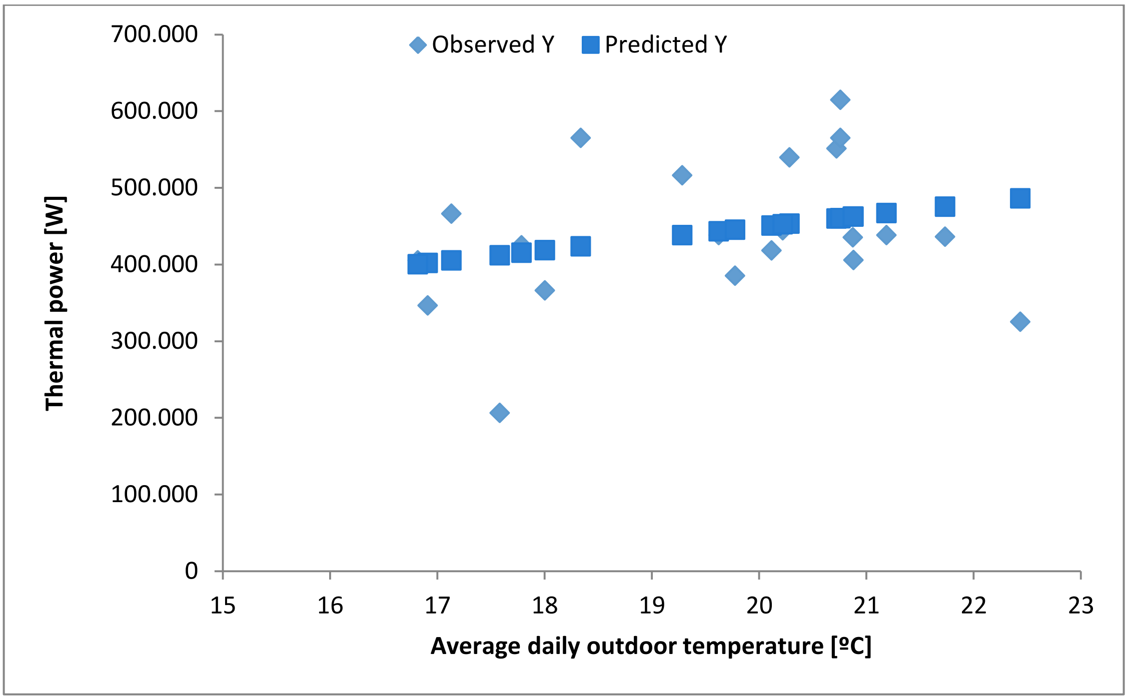

Figure 19: Adjusted regression curve with the outdoor temperature

Seeing the yielded results, this model is directly rejected. Further data exploration and the consideration of additional variables is necessary to improve the accuracy of the regression analysis. The proposal for the next model is to include the an average of the most representative indoor temperatures in CARTIF Building as significant variables in order to evaluate the thermal energy consumption.

Decision making	
Decision	**TO REJECT THE MODEL**
Change proposal	TO INCLUDE THE INDOOR TEMPERATURES IN THE MODEL

Table 26: Summary of the modelling decision making

3.8.2 Model 2

Independent variables

The second model includes the average of the most representative indoor temperatures as independent variable.

- **Outdoor temperature** [°C]: Average daily outdoor temperature obtained from the data registered by the weather station every 1 minute.
- **Indoor temperature** [°C]: Average daily indoor temperature between three of the most representative rooms in CARTIF Building (Vision 2D, Energias2 and Energias1). The data are obtained from the registers (every 1 minute) of the temperature sensors (UBC5, UBC7 and UBC8) installed in the three rooms.

Modelling period

It has been considered the same period than in the first model (August 2014).

Model adjustment

A multiple linear regression analysis is proposed to explain the cooling energy consumption as function of the outdoor and indoor temperatures. The coefficients obtained for the indoor and outdoor temperatures should be positive because when the outdoor and indoor temperatures increase, higher energy is needed to cool the zones of the building.

$$ABE_{SUMMER} = a + b \cdot T_{indoor}[^{\circ}C] + c \cdot T_{out}[^{\circ}C]$$

Equation 8: Adjusted Baseline Energy for the Uc2 of CARTIF pilot building

Analysis of the results and conclusions

Regression statistics	
Coefficient of determination R^2	39%
Adjusted R^2	32%
Standard error SE	77,626
Number of observations	21

Table 27: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	-4,966	1,717,791	-2.89	0.00
b (Indoor temperature)	20,700	67,794	3.05	0.00

c (Outdoor temperature)	8,342	7,820	1.06	0.30

Table 28: Summary of the variance analysis

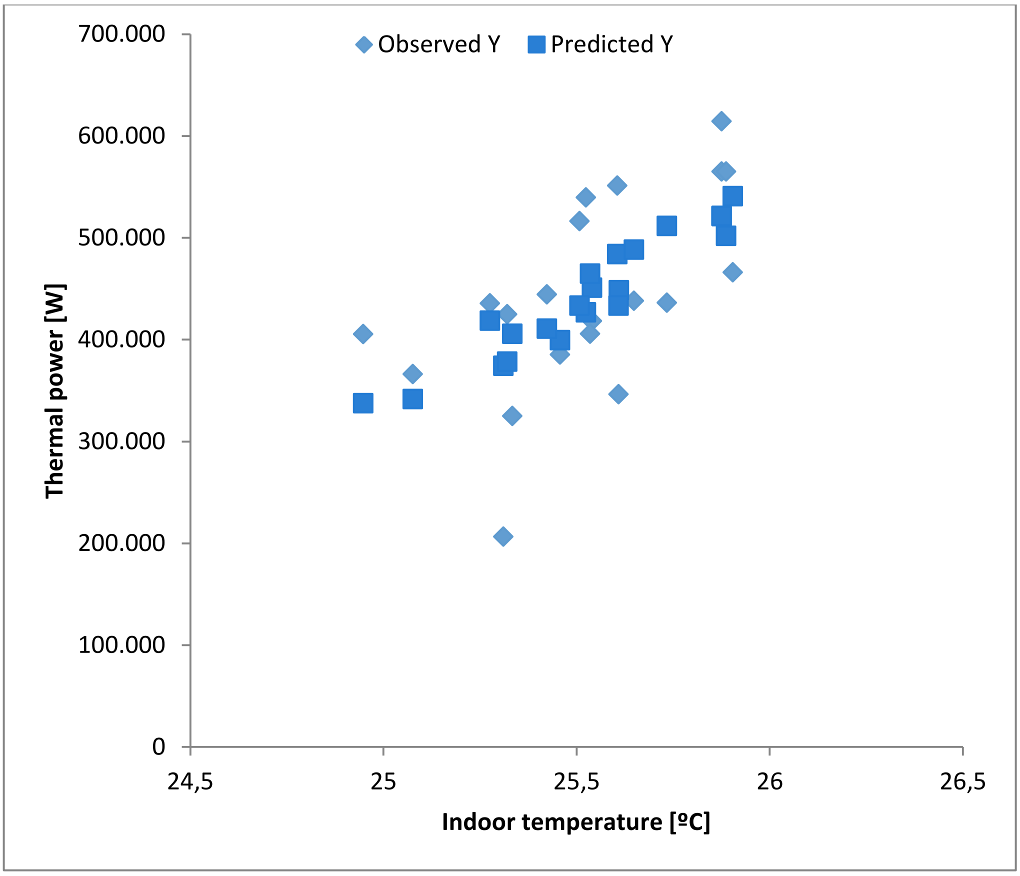

Figure 20: Adjusted regression curve with the average of the indoor temperatures

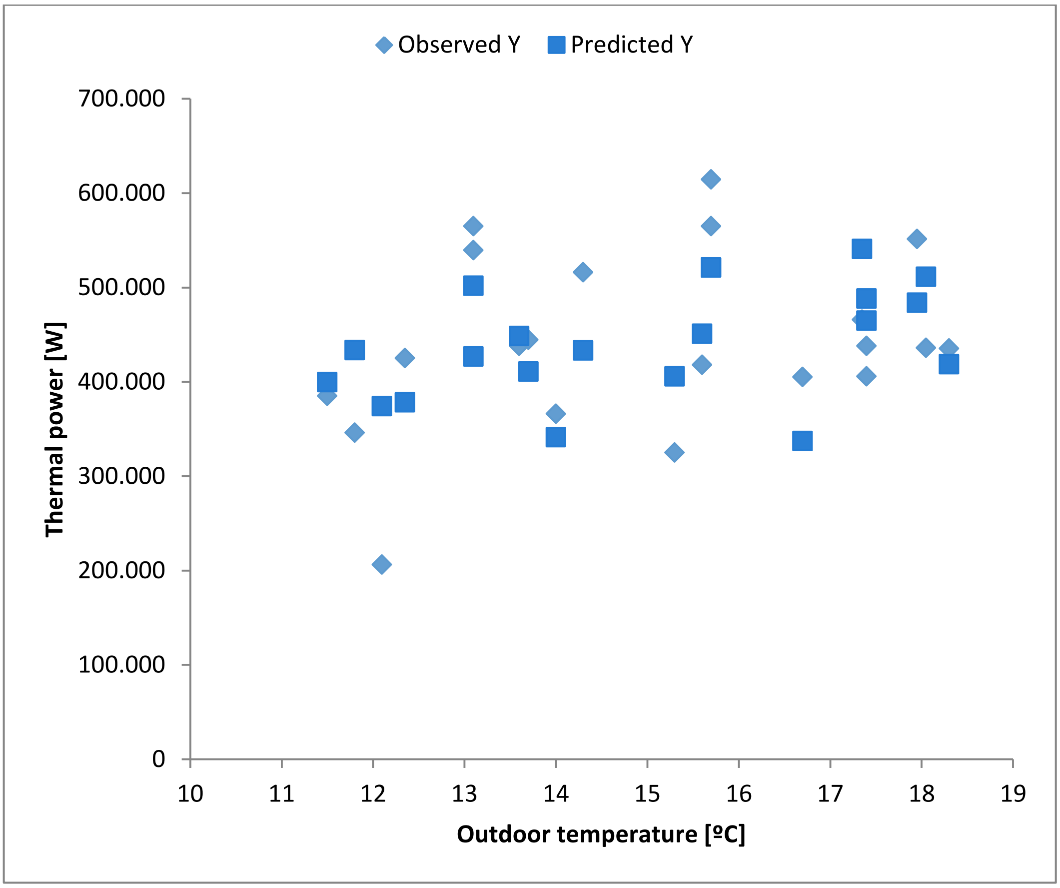

Figure 21: Adjusted regression curve with the average of the outdoor temperatures

The main conclusions of this regression analysis are the following ones:

- The slopes of the indoor and outdoor temperatures are positive which would mean that the higher is the temperatures, the higher is the cooling energy consumption.
- The model is much better than the previous one, but it is still not enough accurate. R^2 do not reach the minimum acceptable level of 75% recommended by the methodology defined in the IPMVP.

In order to improve the model adjustment, the proposal for the following analysis is to include the solar radiation as another independent variable to explain the energy consumption.

Decision making	
Decision	**TO REJECT THE MODEL**
Change proposal	TO INCLUDE THE SOLAR RADIATION IN THE MODEL

Table 29: Summary of the modelling decision making

3.8.3 Model 3

Independent variables

The third model includes the solar radiation as independent variable in order to improve the results of the regression model. In this case the cooling energy consumption is related to the external conditions (weather and radiation) and the internal condition (thermal comfort).

- **Outdoor temperature** [°C]: Average daily outdoor temperature obtained from the data registered by the weather station every 1 minute.
- **Indoor temperature** [°C]: Average daily indoor temperature. Considering the occupancy level and the orientation of CARTIF building, they have been selected three different thermal zones to obtain this indoor temperature: Vision 2D, Energias2 and Energias1. The data are taken from the registers (every 1 minute) of the temperature sensors (UBC5, UBC7 and UBC8) installed in the three zones. There are two rooms (Vision 2D and Energias), but three thermal zones (Vision 2D, Energias 2 and Energias 1).
- **Solar radiation** [W/m^2]: Average solar radiation incident on the CARTIF building, calculated from values of solar radiation registered by the weather station (W/m^2) every minute.

Modelling period

It has been considered the same period than in the first model (August 2014). In the next table are represented the data collected for the independent variables in the evaluated period.

Model adjustment

The model that is proposed is a linear regression to represent the energy consumption as a function of the indoor temperature, outdoor temperature and the solar radiation. The coefficients obtained for the indoor and outdoor temperatures should be positive because higher energy is needed to refresh the zones of the building according to the outdoor and indoor temperatures increase. The coefficient obtained for the solar radiation should be also positive due to the cooling energy consumption increases with the solar radiation received.

$$ABE_{SUMMER} = a + b \cdot T_{ind}[^{\circ}C] + c \cdot T_{out}[^{\circ}C] + d \cdot Rad \ \ [W/m^2]$$

Equation 9: Adjusted Baseline Energy for the Uc2 of CARTIF pilot building

Analysis of the results and conclusions

Regression statistics	
Coefficient of determination R^2	47 %
Adjusted R^2	38 %
Standard error SE	74,625
Number of observations	21

Table 30: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	-6,359	1,840,299	-3.45	0
b (Outdoor temperature)	267,483	75,105	3.56	0
c (Indoor temperature)	-339	189	-1.78	0.09
d (Solar radiation)	9,901	10,375	0.95	0.35

Table 31: Summary of the variance analysis

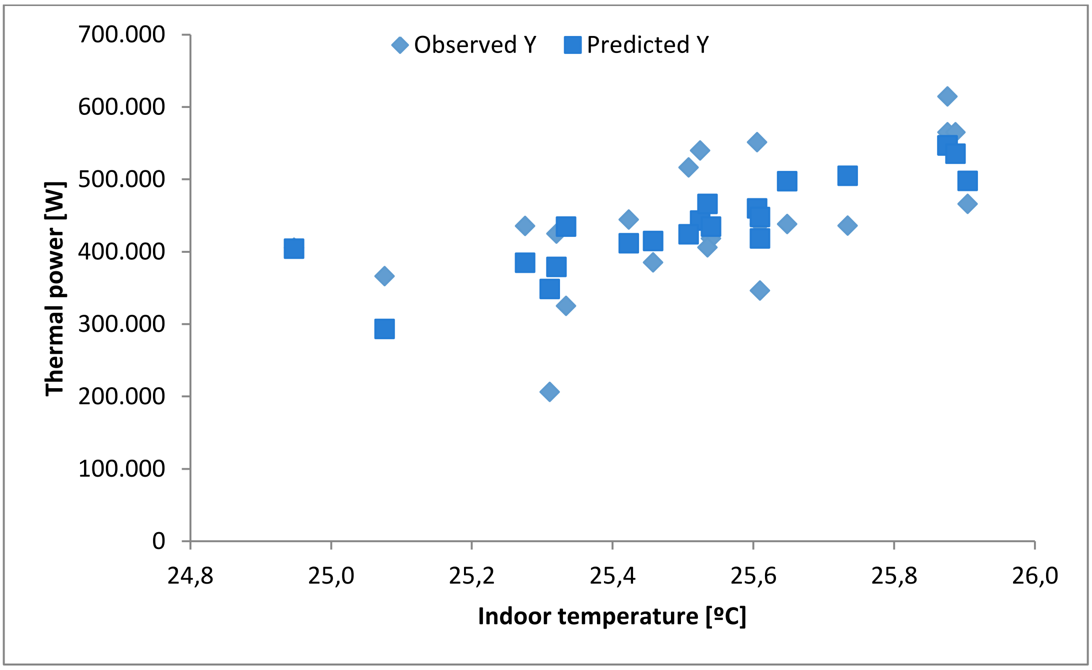

Figure 22: Adjusted regression curve with the average of the indoor temperature

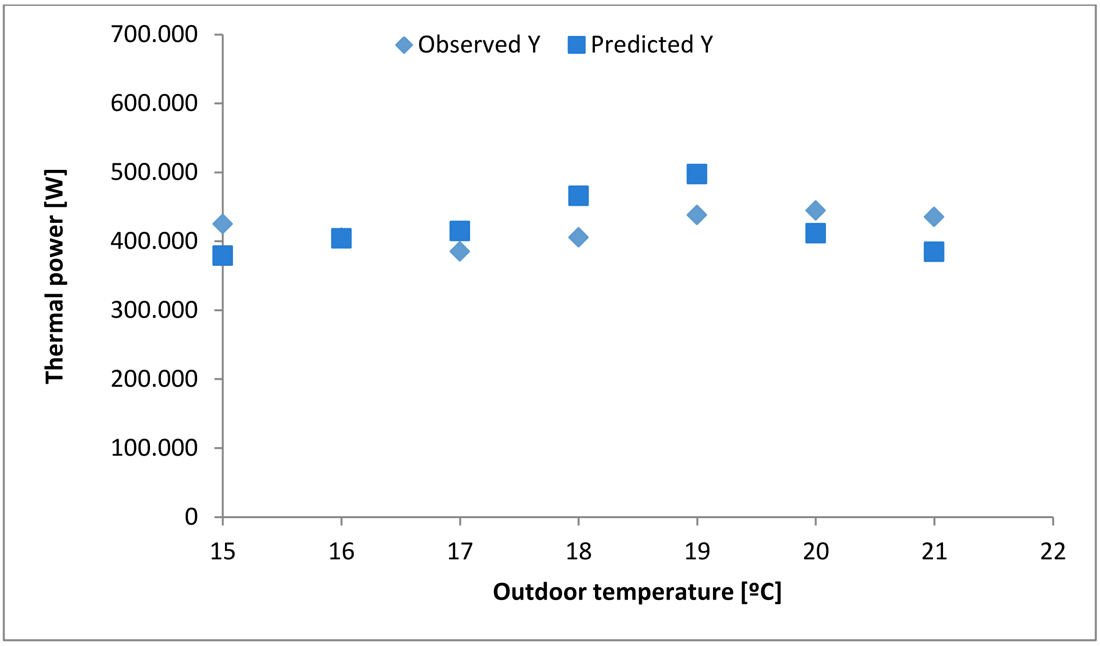

Figure 23: Adjusted regression curve with the average of the outdoor temperature

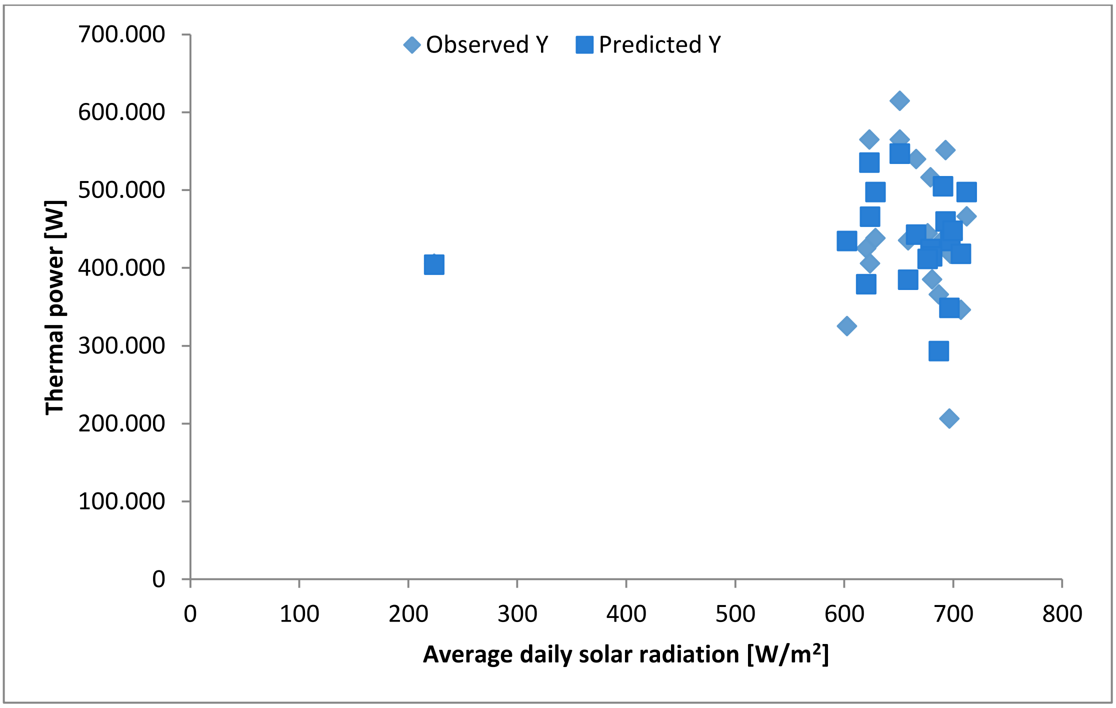

Figure 24: Adjusted regression curve with the average of the solar radiation

The main conclusions of this regression analysis are the following ones:

- The slopes of the indoor temperatures and the solar radiation are positive which would mean that the higher are the radiation and the temperatures, the higher is the cooling energy consumption.
- R^2 do not reach the minimum acceptable level of 75% recommended by the methodology defined in the IPMVP.

The proposal for the next model is to develop a quadratic model with the same independent variables, evaluating the cooling energy consumption during the operating hours. It is also proposed to consider the fact than on Mondays the energy consumption is usually higher.

Decision making	
Decision	**TO REJECT THE MODEL**
Change proposal	TO DEVELOP A QUADRATIC REGRESSION MODEL, USING THE SAME INDEPENDENT VARIABLES TO CONSIDER THE "MONDAY" EFFECT

Table 32: Summary of the modelling decision making

3.8.4 CARTIF ABE_Uc2 Final Model

Independent variables

This regression model includes the same independent variables than the previous one (outdoor temperature, indoor temperature and solar radiation), but in this case it implements a quadratic function.

Modelling period

The modelling period is the same than in the rest of the models for CARTIF_Uc2: August 2014.

Model adjustment

The modelling strategy is to use quadratic multiple regression techniques to predict the cooling energy consumption as function of the indoor temperatures, the outdoor temperature and the solar radiation. The coefficients for the indoor temperature, outdoor temperature and solar radiation should be positive; as they make that the energy demand increase. The variable "Day" is qualitative, and it has been codified to include it in the model taking the value 1 on Mondays and 0 for all other days.

$$ABE_{SUMMER} = a + b \cdot T_{out}[^{\circ}C] + c \cdot T_{indoor}[^{\circ}C] + d \cdot Rad[W/m^2] + \\ e \cdot Day + f \cdot T_{out} x T_{in} + g \cdot T_{out} x Rad + h \cdot T_{out}^{\ 2} + i \cdot T_{in}^{\ 2} + j \cdot Rad^2$$

Equation 10: Adjusted Baseline Energy for the Uc2 of CARTIF pilot building

Analysis of the results and conclusions

Regression statistics	
Coefficient of determination R^2	79%
Adjusted R^2	57%
Standard error SE	0.57
Number of observations	21

Table 33: Summary of the regression statistics

	Coefficient	SE
a (Intercept)	355,458	194,220,901
b (Outdoor temperature)	1,057,195	1,195,232
c (Indoor temperature)	-26,729,488	14,502,805
d (Solar radiation)	-81,230	67,272
e (Day)	2,119	39,139
f (Outdoor temperature x Indoor temperature)	-19,396	49,156
g (Outdoor temperature x Solar radiation)	306	357
h (Outdoor temperature x Outdoor temperature)	3,294	2,899
i (Indoor temperature x Indoor temperature)	-19,374	10,053
j (Solar radiation x Solar radiation)	492,642	273,705

Table 34: Summary of the variance analysis

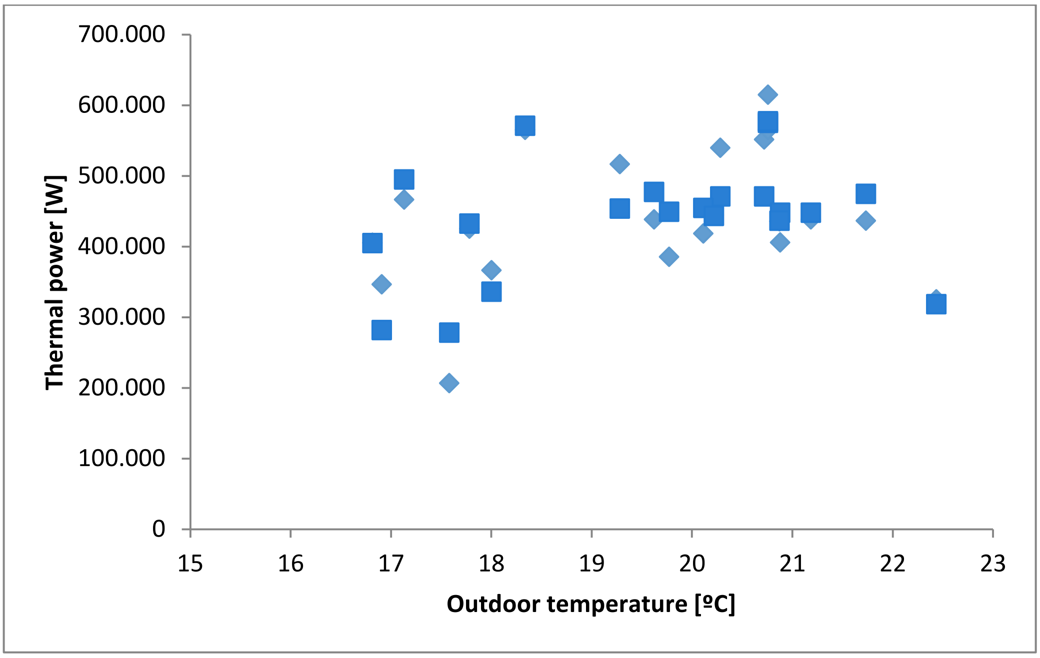

Figure 25: Adjusted regression curve with the average of the outdoor temperature

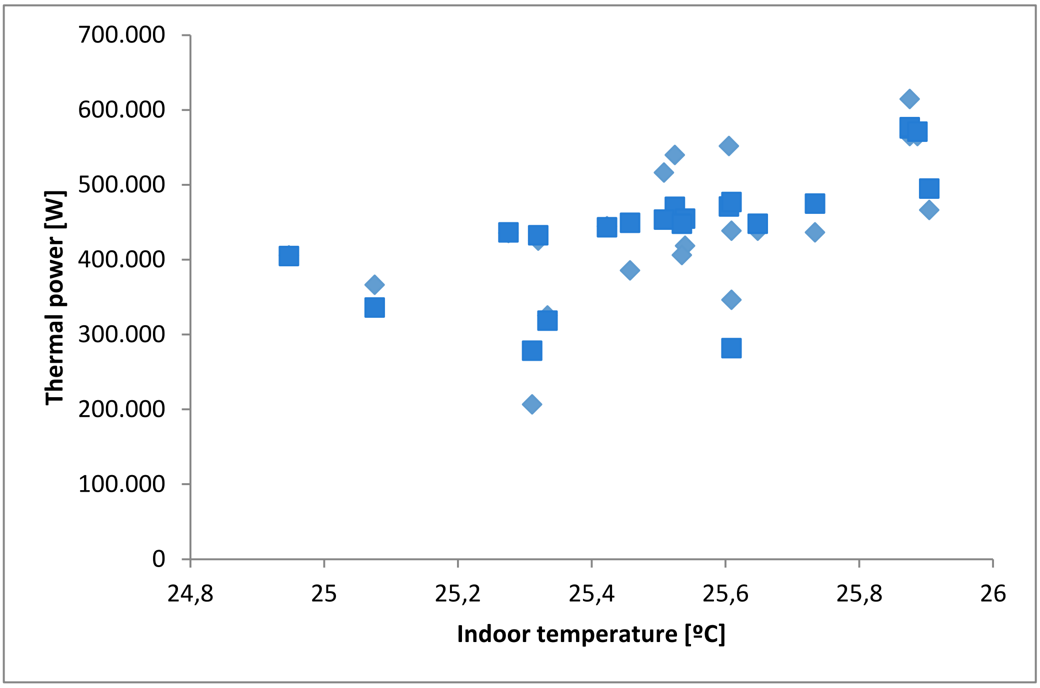

Figure 26: Adjusted regression curve with the average of the indoor temperature

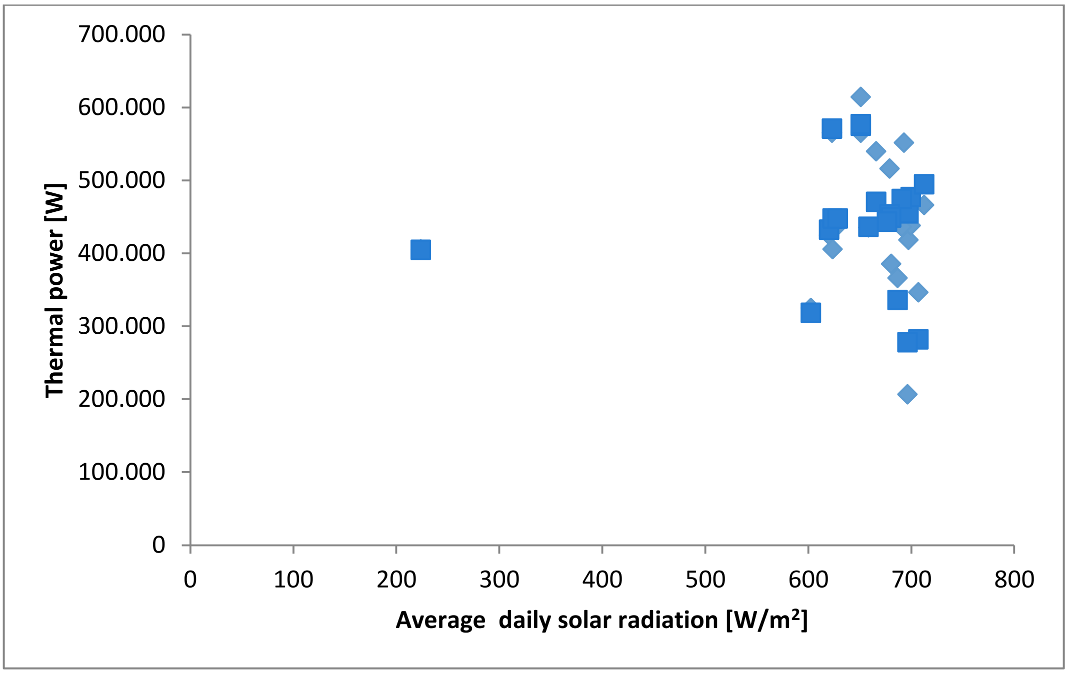

Figure 27: Adjusted regression curve with the average of the solar radiation

The main conclusions that can be drawn from the regression analysis are the following ones:

- The sign of the coefficient or slope for the independent variables are positive that means that the model is consistent from an energy consumption point of view. This aspect is essential to support the validity of the obtained model, together with the checking of the statistic tests.
- The R^2 obtained in this regression analysis is 79%, which means that the model explains quite well the variability of the cooling energy consumption with the independent variables included. This value is more than acceptable, as it far overcomes the minimum level recommended by the IPMVP methodology is 75%.

On the basis of the above, this model can be accepted and will be considered as the definitive one.

Decision making	
Decision	**TO ACCEPT THE MODEL AND CONSIDER IT AS VALID TO APPLY THE IPMVP FOR CARTIF UC2**

Table 35: Summary of the modelling decision making

The next equation represents the ABE for the Uc2 in CARTIF pilot buildings and will be used to evaluate the energy savings achieved, following the IPMVP guidelines.

$$P[W] = 355{,}458 + 1{,}057{,}195 \cdot T_{out}[^{o}C] + \text{-}26{,}729{,}488 \cdot T_{indoor}[^{o}C] + \text{-}81{,}230 \cdot Rad[W/m^{2}] + 2{,}119 \cdot \cdot Day + \text{-}19{,}396 \cdot T_{out} x T_{in} + 306 \cdot T_{out} x Rad + 3{,}294 \cdot T_{out}{}^{2} + \text{-}19{,}374 \cdot T_{in}{}^{2} + 492{,}642 \cdot Rad^{2}$$

Equation 11: Adjusted Baseline Energy for the Uc2 of CARTIF pilot building

4 ZUB Pilot Building

4.1 Description of the energy system

The ZUB building is equipped with radiant slabs situated in ceilings and floors of each room with the two systems operated independently, and in combination with the Air Handling Unit that control the external air renovations, as it can be observed in the scheme of the following figure.

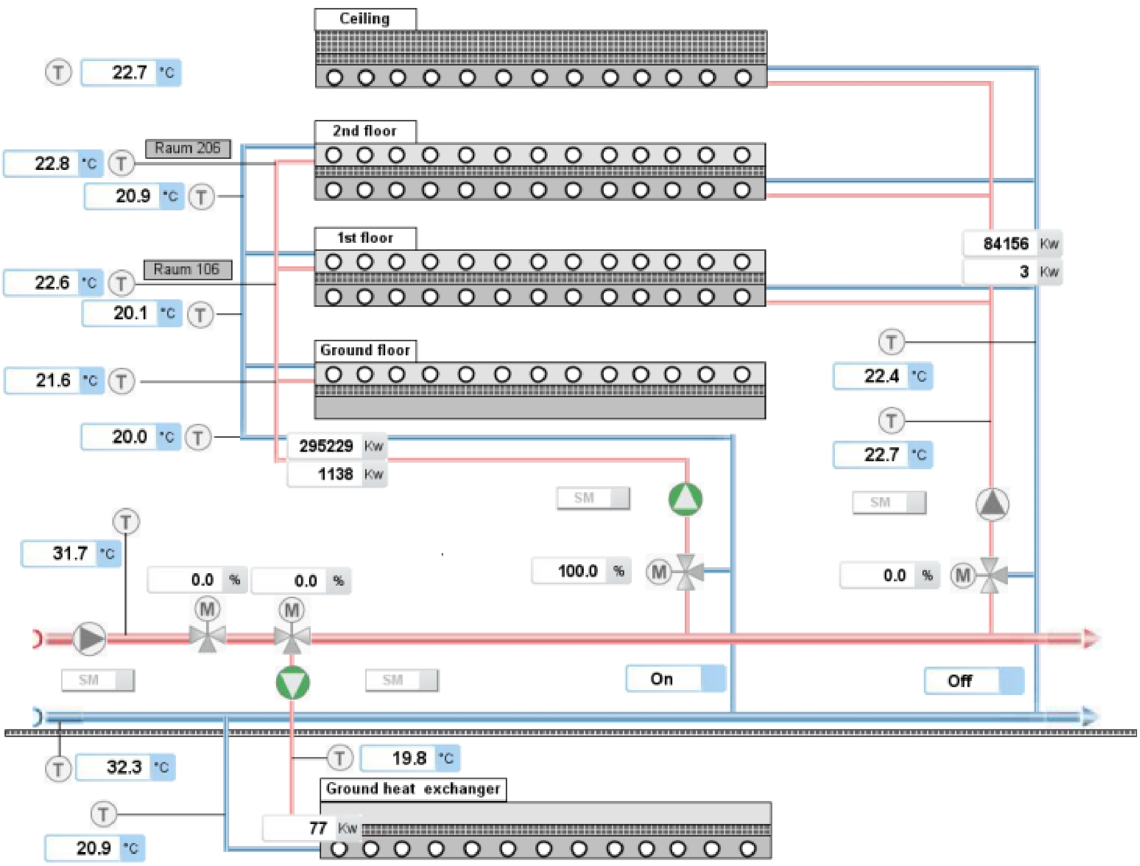

Figure 28: Schema of the radiant distribution in ZUB Building.

Both systems share a common distribution system that delivers cooling from an active ground exchanger during warm periods and heating provided by the Kassel's University district heating ring during the cold season.

Since the building has been gone into operation in 2001, there is already a high level of monitoring due to the more of 700 sensors installed. The performance of the building with its conventional control strategy and design is well known. All energy supply systems as well as most comfort aspects are already monitored. Due to this, it is expected that only a small number of sensors need to be integrated into the building management systems in order to be able to evaluate the BaaS system. However, the number of different energy supply concepts realized in the building is relatively low. This limits the degree of freedom in optimizing the building control and can only lead to an energy efficient building due to its high insulation standard and high inertia of the structure. The south façade and its exterior venetian blinds permit the optimization of daylight and artificial light concept in the occupied zones.

4.2 IPMVP Specification

The previous document *"D6.3.1 Measure and Verification Plan"* describes the methodology that will be applied to evaluate the BaaS solution and calculate the energy savings obtained with the implementation of the ECMs that this solution includes.

In the case of ZUB pilot building, it is possible to measure and evaluate at ECM level with different energy meters installed. BaaS solution combines different energy systems with different functionalities, and therefore it is not possible to isolate with meters. In addition, some inefficiencies have been detected in the energy systems, being the expected energy savings around 15 % (more than 10%). Finally, all the ECMs implemented in the building are related with the BaaS solution, and thus, it is not necessary to assess each one separately.

With all these considerations, the selection process described in the IPMVP leads to choose the "***Option C: Whole Facility***". In this option of the IPMVP, the energy savings are calculated analysing the whole facility utility meter or sub-meter data using techniques from simple comparison of the energy consumptions to regression analysis, referencing these consumptions to external and internal conditions.

4.3 Measurement Boundary

The measurement boundary is determined by the choice of IPMVP Option. In the case of ZUB pilot building, as Option C has been selected, the energy meters considered are the ones that measure the total energy consumptions: heat (from the district heating) and electricity (from the electrical network).

Building	Measurement Boundary
ZUB Building	Thermal Energy Consumption from District Heating.

Table 36: Measurement Boundary

The specific energy meters that are considered to evaluate energy savings in ZUB Building are:

- H1: Heat meter that measure energy consumption from District Heating.

In order to apply the Option C of IPMVP, the data obtained from H1 meter will be used to develop a mathematical model that estimates the thermal energy consumptions.

4.4 Baseline period

The baseline period should represent all operating models of the building. The length of the baseline period should be such that it contains all situations of building energy consumption. Each building has a different use and could have a different baseline period, where all energy profiles can be.

In order to determine the reference period for ZUB pilot building, it is necessary to consider the use cases that have been proposed, the occupation profiles of the building and weather conditions. ZUB Building is an offices building that has heating and cooling systems and it is located in Kassel (Germany). The energy consumption of the building mainly depends on occupancy and weather. The building is occupied from 08:00 to 17:00 from Monday to Friday, being closed during the weekend. Nevertheless, studying the available data it can be observed that there is energy consumption also on Saturdays and Sundays, and hence, the corresponding data points should be considered in the analysis too.

The baseline period that has been considered to apply the IPMVP in ZUB pilot building is one year, from October 2013 to September 2014.

Start of baseline period	End of baseline period
1st October, 2013	30th September, 2014

Table 37: ZUB Building baseline period

4.5 Independent Variables

Energy consumption in ZUB pilot building depends mainly on weather conditions and occupation. Weather conditions are *independent variables* that are related to energy consumption. ZUB pilot building has passive systems to storage energy and has a big influence of solar radiation, due to his building design. Therefore, the variables that will be considered for the modelling are the outdoor temperature and the solar radiation.

1st Independent Variable	2nd Independent Variable
Outdoor temperature	Solar radiation

Table 38: ZUB Building independent variables

4.6 Static Factors

Static factors are those parameters that describe the installation and operation of the building and remain constant coinciding with baseline period, from energy consumption point of view. They include different types and some of the most important are the following ones:

- **Building characteristics**: It is assumed that they do not change during the period under study.
- **Equipment inventory**: It is considered that it is the same during the period under study.
- **Occupancy**: The building is occupied from 08:00 to 17:00 from Monday to Friday, being closed during the weekend. Nevertheless, studying the available data it can be observed that there is energy consumption also on Saturdays and Sundays, and hence, the corresponding data points should be considered in the analysis too.
- **Operating conditions**: Predefined.

For more details, all static factors considered for ZUB Building have been defined in Deliverable 6.1 Appendix A.

4.7 Adjusted Baseline Energy for ZUB Use Case 1

The aim of this section is to obtain a mathematical model that allows relating the thermal energy consumption with external conditions, which also affect to the comfort level inside the building. This energy model will be used to evaluate the energy savings achieved with the BaaS solution, comparing the baseline and the reporting periods following the guidelines defined in the IPMVP.

Within the external conditions, the most important ones are the weather parameters. The factors that are supposed to have a more clear influence on the problem under study are the outdoor temperature and the solar radiation.

In addition, including the solar radiation in the regression model enables the study of the contribution that the solar energy has on the energy savings. This issue is directly related with the Use Case 1 that has been proposed for ZUB pilot building, which deals with the utilization of solar energy for energy savings while ensuring visual and thermal comfort.

$$H[kWh] = a - b \cdot T_{out}[^{o}C] - c \cdot Rad[kWh/m^{2}]$$

Equation 12: ZUB Building: Adjusted Baseline Energy

4.7.1 Model 1

Independent variables

- **Outdoor temperature** [°C]: Average daily outdoor temperature obtained from the data registered by the weather station installed on the roof of ZUB pilot building every 5 minutes.
- **Solar radiation** [kWh/m^2]: Total daily solar radiation incident on the ZUB building, calculated as the sum of values of solar radiation registered by the weather station (W/m^2) installed on the roof of ZUB pilot building every 5 minutes.

Modelling period

In order to do an initial analysis of the problem, a model based on the gathered data from January-February-March of 2014 has been developed.

Modelling considerations	
Period	1st January 2014 – 31st March 2014
Frequency	Daily (a day corresponds to a point of the model)

Table 39: Modelling period and frequency

Model adjustment

The modelling strategy is to use multiple linear regression techniques to obtain a linear model that can predict the thermal energy that ZUB pilot building consumes from the DH network as function of the outdoor temperature and the solar radiation. This functional form (linear) is preferable due to its simplicity and the energy sense.

The coefficients obtained for the outdoor temperature and solar radiation should be negative; as they make that the demand of thermal energy from the DH network decreases.

Analysis of the results and conclusions

The main features obtained from the regression analysis are summarized in the following tables:

Regression statistics	
Coefficient of determination R^2	72%
Adjusted R^2	72%
Standard error SE	46.0
Number of observations	90

Table 40: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	334.3	14.0	23.92	0.00
b (Slope for the outdoor temperature)	-20.4	2.4	-8.58	0.00
c (Slope for the solar radiation)	-23.0	4.9	-4.74	0.00

Table 41: Summary of the variance analysis

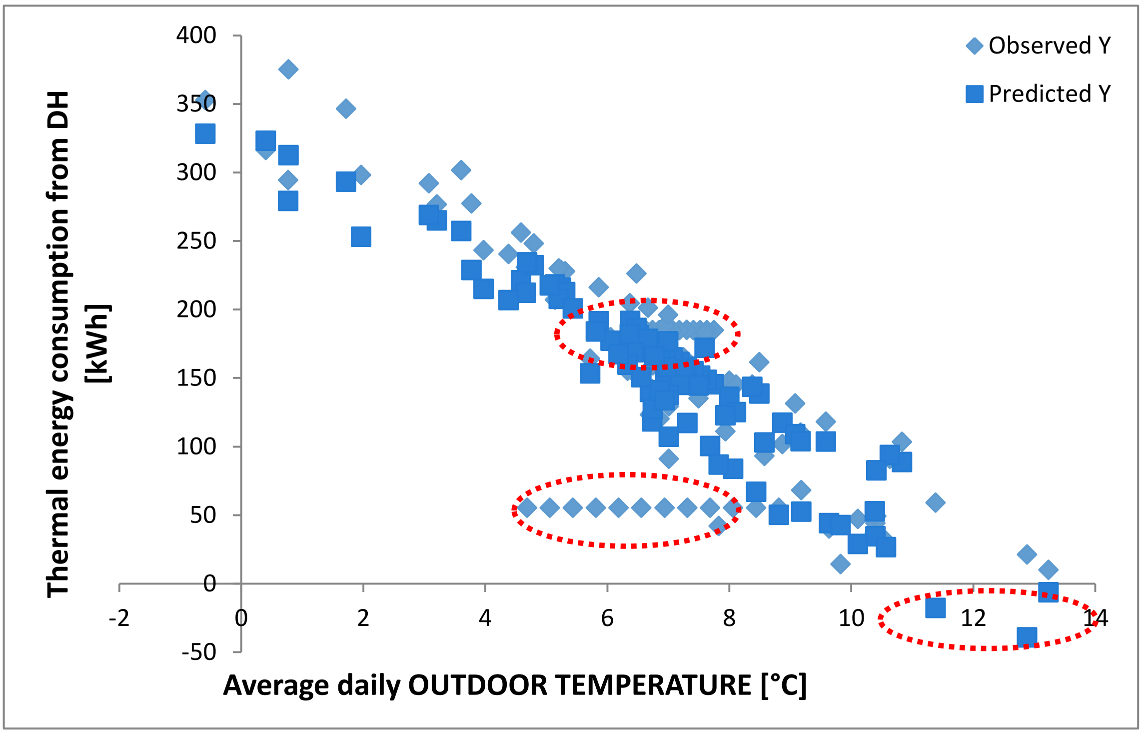

Figure 29: Adjusted regression curve with the outdoor temperature

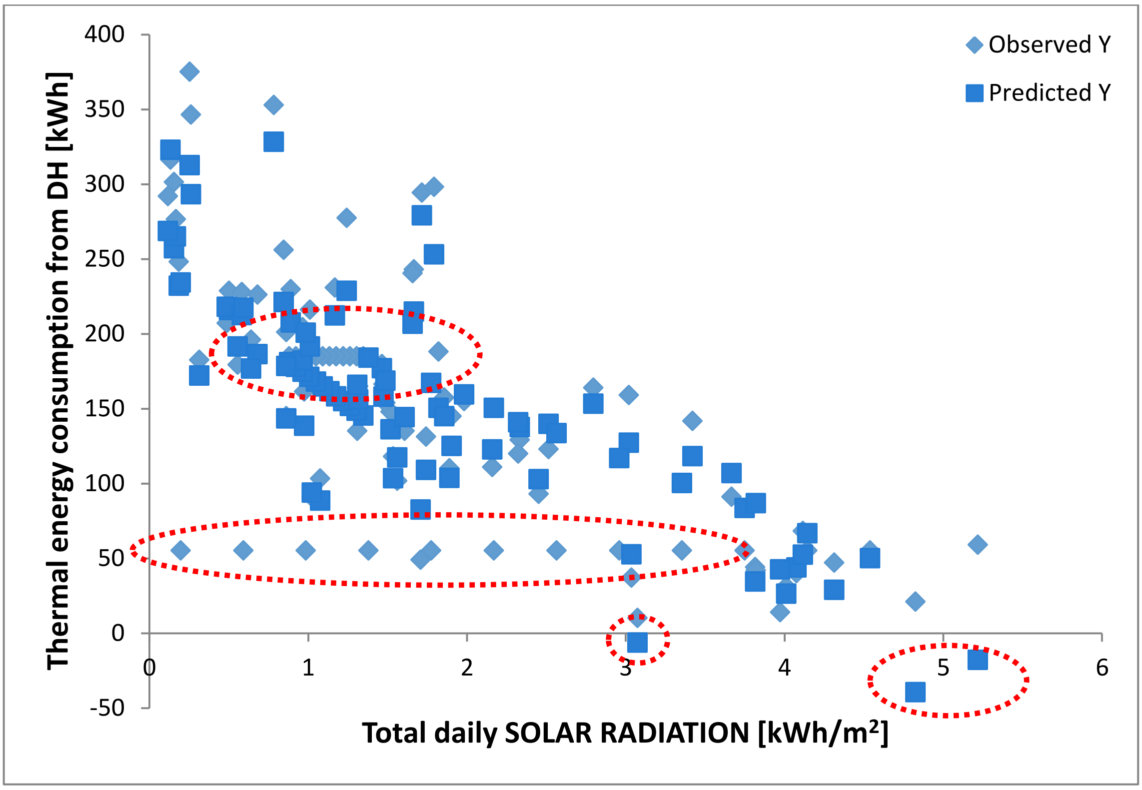

Figure 30: Adjusted regression curve with the solar radiation

The main conclusions that can be drawn from the regression analysis are the following ones:

- The sign obtained for the coefficients is the right one, both for the outdoor temperature and the solar radiation. However, the model cannot be taken valid because it predicts negative energy consumptions for the highest values of outdoor temperature and solar radiation.
- It can be observed that some data points are not consistent. For example, the first two weeks of January and another week in March present the exactly the same energy consumption all the days, almost not variation in the outdoor temperature and solar radiations different than zero during the night (remarked with red circles in the graph). This issue may indicate that the installation was off or reset due to the Christmas bank holidays and the beginning of the year, or even measurement errors. Therefore, the considered period is not representative as it has some faults and inconsistencies. Further data exploration should be carried out in order to include in the model only those days that are significant and consistent.
- The R^2 obtained in this regression analysis is 72%, which is under the minimum level recommended by the IPMVP methodology (75%).
- The t-statistic are very good and far greater than 2 for all the estimations in absolute value and p-values are almost null for all the independent variables (outdoor temperature and solar radiation), which mean that both variables are significant for the explanation of the energy consumption.

On the basis of the above, this model has to be rejected. Further analysis and data exploration must be done in order to select a more representative period to adjust the model.

Decision making	
Decision	**TO REJECT THE MODEL**
Change proposal	FURTHER DATA EXPLORATION IN ORDER TO SELECT A SAMPLING PERIOD BOTH REPRESENTATIVE AND CONSISTENT

Table 42: Summary of the modelling decision making for ZUB_Uc1

4.7.2 Model 2

Independent variables

The same variables than in Model 1 have been considered: outdoor temperature and solar radiation.

Modelling period

Taking into account the analysis results and the conclusions drawn from the previous model, it is considered that the month of January may be not representative (data inconsistencies, Christmas holidays, start-up of the systems, etc.) and hence, it will not be included in this model. For this reason, the second model that has been developed for ZUB_Uc1 is based on the data gathered during February and March of 2014.

Regression statistics	
Period	1st February 2014 – 31st March 2014
Frequency	Daily (a day corresponds to a point of the model)

Table 43: Modelling period and frequency

Model adjustment

For this model the mathematical expression and the interpretation of the signs is the same than in Model 1.

Analysis of the results and conclusions

The main features obtained from the regression analysis are summarized in the following tables:

Regression statistics	
Coefficient of determination R^2	47%
Adjusted R^2	47%
Standard error SE	48.23
Number of observations	59

Table 44: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	255.66	24.91	10.26	0.00
b (Slope for the outdoor temperature)	-13.03	3.75	-3.47	0.00
c (Slope for the solar radiation)	-18.99	6.10	-3.11	0.00

Table 45: Summary of the variance analysis

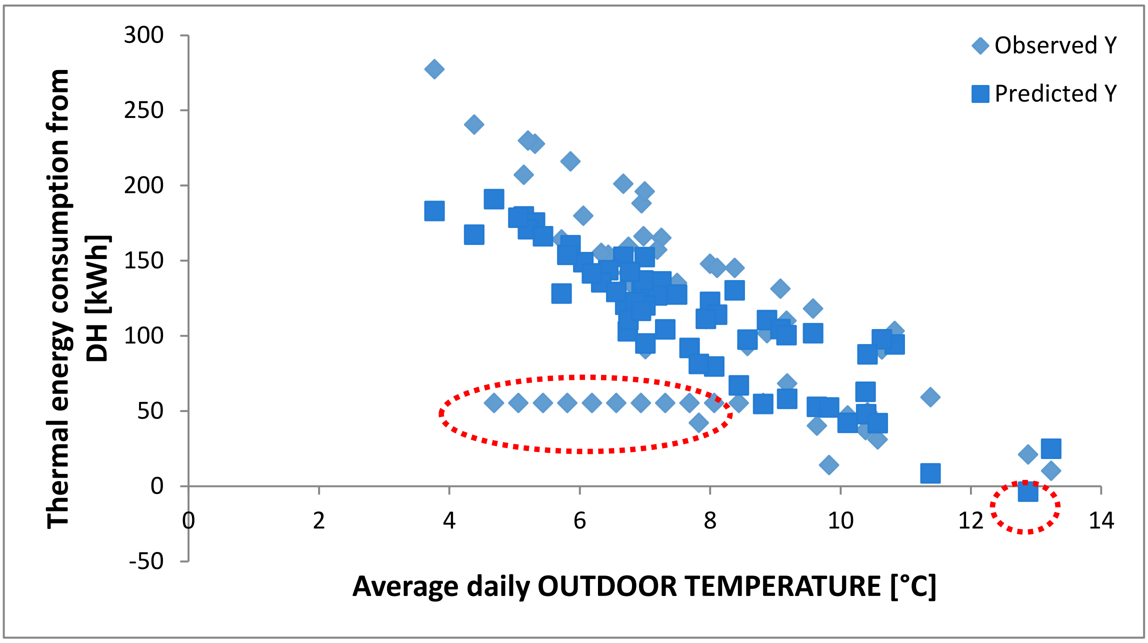

Figure 31: Adjusted regression curve with the outdoor temperature

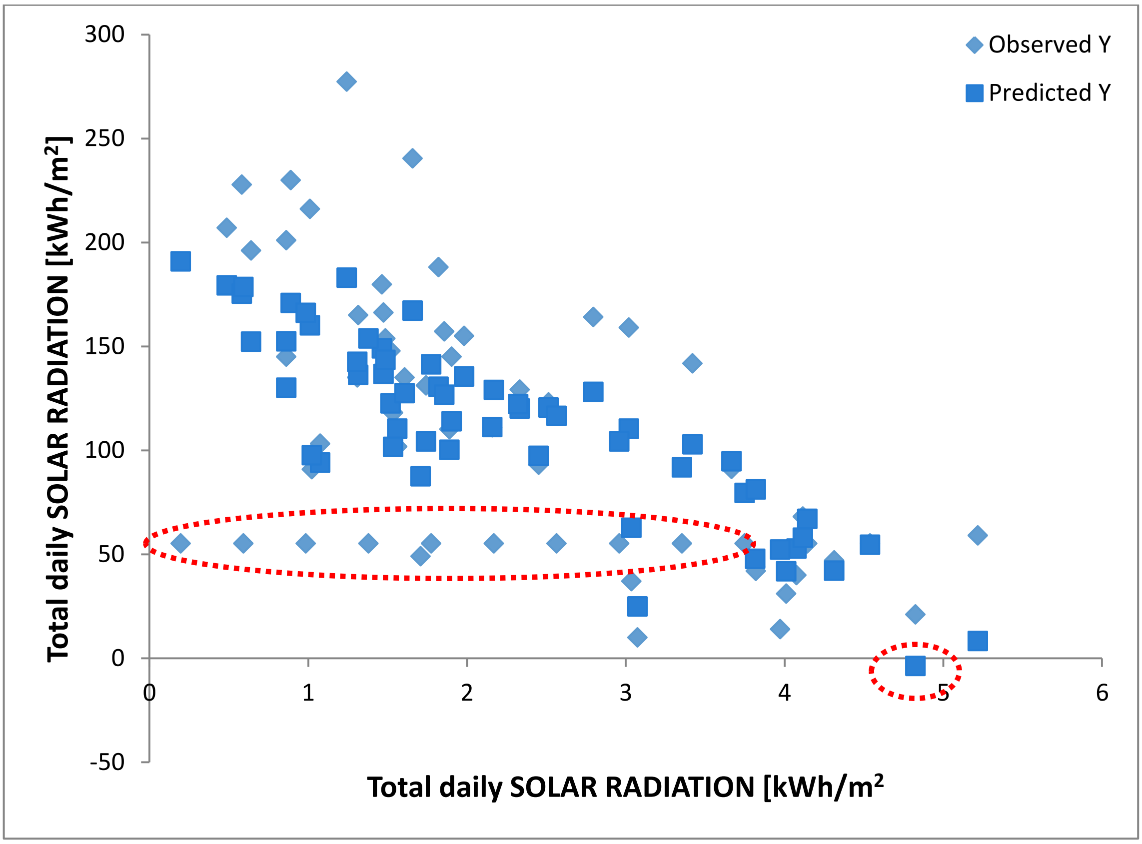

Figure 32: Adjusted regression curve with the solar radiation

The main conclusions that can be drawn from the regression analysis are the following ones:

- The sign obtained for the coefficients is the right one, both for the outdoor temperature and the solar radiation. However, the model cannot be taken valid because it predicts negative energy consumptions for the highest values of outdoor temperature and solar radiation.
- It can be observed that some data points are not consistent (remarked with red circles in the graph). This issue may indicate that the installation was off or reset in those days or measurement errors. Therefore, the considered period is not representative as it has some faults and inconsistencies. Further data exploration should be carried out in order to include in the model only those days that are significant and consistent.
- The R^2 obtained in this regression analysis is 47%, which is very low and under the minimum level recommended by the IPMVP methodology (75%).
- The t-statistic are very good and far greater than 2 for all the estimations in absolute value and p-values are almost null for all the independent variables (outdoor temperature and solar radiation), which mean that both variables are significant for the explanation of the energy consumption.

On the basis of the above, this model has to be rejected. Further analysis and data exploration must be done in order to select a more representative period to adjust the model.

Decision making	
Decision	**TO REJECT THE MODEL**

Change proposal	FURTHER DATA EXPLORATION IN ORDER TO SELECT A SAMPLING PERIOD BOTH REPRESENTATIVE AND CONSISTENT

Table 46: Summary of the modelling decision making for ZUB_Uc1

4.7.3 Model 3

Independent variables

The same variables are considered in this model: outdoor temperature and solar radiation.

Modelling period

After studying of the DH thermal energy consumption, outdoor temperature and solar radiation profiles daily, weekly and monthly during the heating season 2013-2014, it has been concluded that the most representative period for the winter season, and also the most consistent in terms of values ranges and evolution, within the baseline period is from the middle of January (after Christmas bank holidays) to the middle April.

Regression statistics	
Period	13th January 2014 – 17th April 2014
Frequency	Daily (a day corresponds to a point of the model)

Table 47: Modelling period and frequency

Model adjustment

For this model the mathematical expression and the interpretation of the signs is the same than in Model 1.

Analysis of the results and conclusions

The main features obtained from the regression analysis are summarized in the following tables:

Regression statistics	
Coefficient of determination R^2	86%
Adjusted R^2	86%
Standard error SE	36.66
Number of observations	83

Table 48: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value

a (Intercept)	330.45	9.54	34.64	0.00
b (Slope for the outdoor temperature)	-19.98	1.26	-15.89	0.00
c (Slope for the solar radiation)	-16.97	3.16	-5.37	0.00

Table 49: Summary of the variance analysis

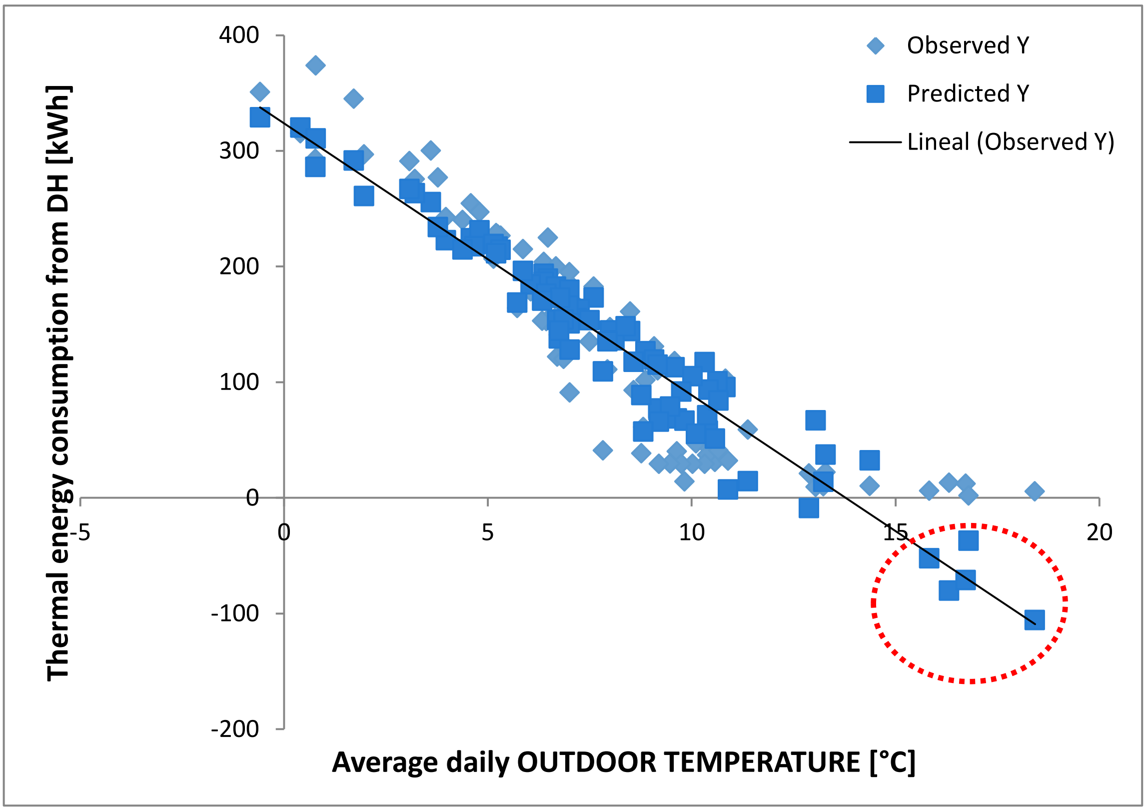

Figure 33: Adjusted regression curve with the outdoor temperature

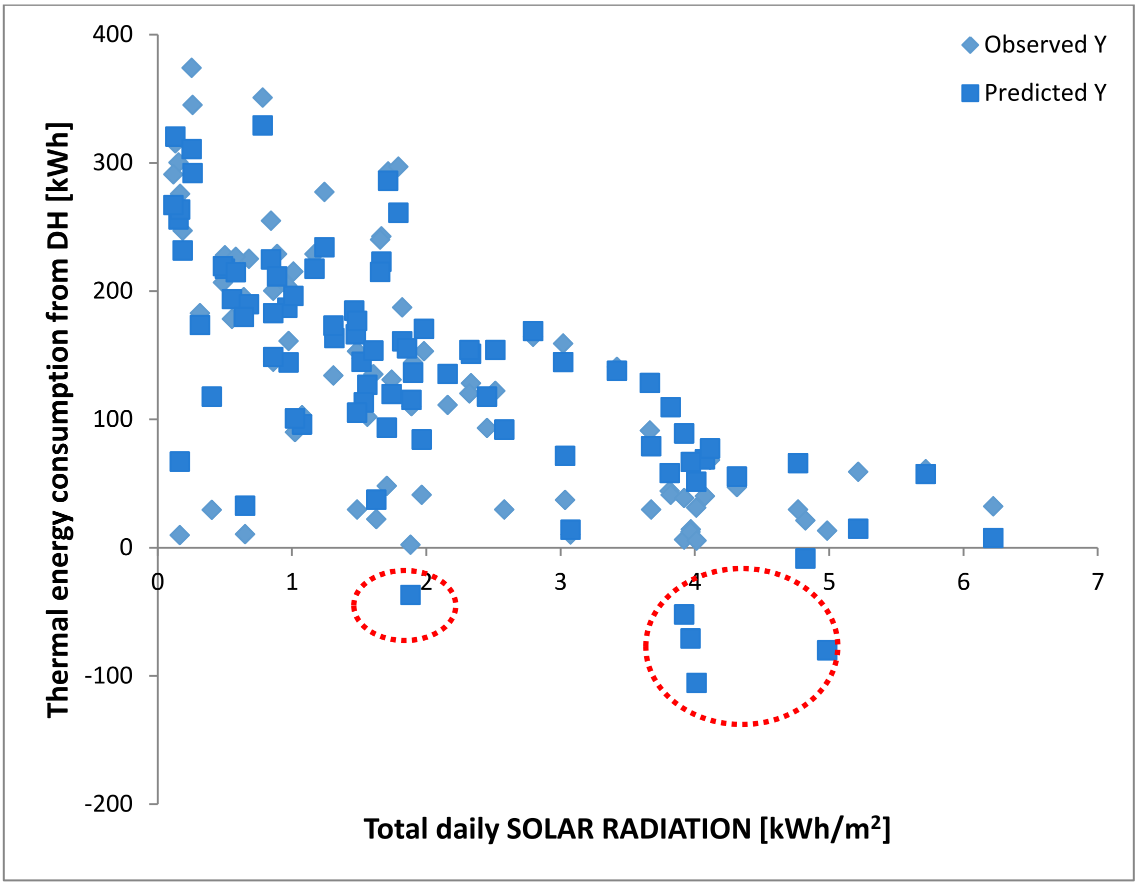

Figure 34: Adjusted regression curve with the solar radiation

The main conclusions that can be drawn from the regression analysis are the following ones:

- The sign obtained for the coefficients is the right one, both for the outdoor temperature and the solar radiation. However, the model cannot be taken valid because it predicts negative energy consumptions for the highest values of outdoor temperature and solar radiation, as it has been remarked in red in the above figures.
- The R^2 obtained in this regression analysis is 86%, which is means that the model represents very well the variability of the thermal energy consumption. It far overcomes the minimum level recommended by the IPMVP methodology (75%).
- The t-statistic are very good and far greater than 2 for all the estimations in absolute value and p-values are almost null for all the independent variables (outdoor temperature and solar radiation), which mean that both variables are significant for the explanation of the energy consumption.

On the basis of the above, despite the fact that from a statistical point of view this model is very representative and accurate, it has to be rejected because it predicts negative values of energy consumption for some levels of outdoor temperature and solar radiation.

Further analysis and data exploration must be done in order to select a more representative period to adjust the model.

Decision making

Decision	TO REJECT THE MODEL
Change proposal	FURTHER DATA EXPLORATION IN ORDER TO SELECT A SAMPLING PERIOD BOTH REPRESENTATIVE AND CONSISTENT

Table 50: Summary of the modelling decision making for ZUB_Uc1

4.7.4 ZUB ABE_Uc1 Final Model

Independent variables

- **Outdoor temperature** [°C]: Average daily outdoor temperature obtained from the data registered by the weather station installed on the roof of ZUB pilot building every 5 minutes.
- **Solar radiation** [kWh/m^2]: Total daily solar radiation incident on the ZUB building, calculated as the sum of values of solar radiation registered by the weather station (W/m^2) installed on the roof of ZUB pilot building every 5 minutes.

Modelling period

After the previous data analyses, it has been concluded that the most representative period for the winter season, and also the most consistent in terms of values ranges and evolution, within the baseline period is from the middle of January (after Christmas bank holidays) to the beginning of March. Selecting this period, the inconsistencies found at the beginning of January and at the middle of March are avoided, getting a consistent and more representative sample for the modelling.

Regression statistics	
Period	13th January 2014 – 7th March 2014
Frequency	Daily (a day corresponds to a point of the model)

Table 51: Modelling period and frequency

Date	Day	DH heat [kWh]	T_{out} [°C]	Rad [kWh/m^2]
13.01.14	Monday	178.2	6.38	0.56
14.01.14	Tuesday	225.0	6.48	0.68
15.01.14	Wednesday	203.9	6.37	0.97
16.01.14	Thursday	182.6	7.60	0.32
17.01.14	Friday	161.0	8.50	0.98

18.01.14	Saturday	254.6	4.59	0.85
19.01.14	Sunday	227.6	5.25	0.50
20.01.14	Monday	300.0	3.61	0.16
21.01.14	Tuesday	275.6	3.21	0.17
22.01.14	Wednesday	247.0	4.80	0.19
23.01.14	Thursday	290.9	3.08	0.12
24.01.14	Friday	345.0	1.72	0.26
25.01.14	Saturday	350.7	-0.59	0.78
26.01.14	Sunday	315.0	0.41	0.13
27.01.14	Monday	242.5	3.98	1.67
28.01.14	Tuesday	228.7	4.67	1.17
29.01.14	Wednesday	373.8	0.78	0.25
30.01.14	Thursday	293.0	0.77	1.72
31.01.14	Friday	296.7	1.97	1.79
01.02.14	Saturday	206.5	5.15	0.49
02.02.14	Sunday	178.5	6.06	1.47
03.02.14	Monday	277.0	3.77	1.24
04.02.14	Tuesday	226.5	5.32	0.58
05.02.14	Wednesday	240.0	4.38	1.66
06.02.14	Thursday	101.7	8.87	1.56
07.02.14	Friday	103.0	10.83	1.08
08.02.14	Saturday	147.5	8.00	1.52
09.02.14	Sunday	164.0	7.25	1.32
10.02.14	Monday	215.0	5.86	1.01
11.02.14	Tuesday	200.0	6.67	0.86

12.02.14	Wednesday	187.0	6.95	1.82
13.02.14	Thursday	195.0	7.00	0.64
14.02.14	Friday	157.0	7.19	1.86
15.02.14	Saturday	89.8	10.64	1.02
16.02.14	Sunday	144.0	8.11	1.90
17.02.14	Monday	166.0	6.98	1.48
18.02.14	Tuesday	228.8	5.21	0.89
19.02.14	Wednesday	144.7	8.38	0.86
20.02.14	Thursday	118.0	9.58	1.54
21.02.14	Friday	130.7	9.08	1.74
22.02.14	Saturday	152.8	6.44	1.49
23.02.14	Sunday	128.0	7.01	2.33
24.02.14	Monday	140.8	6.74	3.42
25.02.14	Tuesday	93.0	8.58	2.45
26.02.14	Wednesday	48.0	10.42	1.71
27.02.14	Thursday	110.0	9.17	1.89
28.02.14	Friday	135.0	7.50	1.61
01.03.14	Saturday	111.0	7.94	2.16
02.03.14	Sunday	122.0	6.70	2.51
03.03.14	Monday	134.0	6.78	1.31
04.03.14	Tuesday	164.0	5.72	2.80
05.03.14	Wednesday	119.9	6.86	2.32
06.03.14	Thursday	152.9	6.33	1.98
07.03.14	Friday	159.0	6.75	3.02

Table 52: Data summary of the modelling period

Model adjustment

As in the previous analyses, a linear model that represents the thermal energy consumption as a function of the outdoor temperature and the solar radiation has been considered.

Analysis of the results and conclusions

The main features obtained from the regression analysis are summarized in the following tables:

Regression statistics	
Coefficient of determination R^2	94%
Adjusted R^2	93%
Standard error SE	18.93
Number of observations	54

Table 53: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	370.08	6.96	53.17	0.00
b (Slope for the outdoor temperature)	-23.82	1.08	-22,00	0.00
c (Slope for the solar radiation)	-25.32	3.57	-7.10	0.00

Table 54: Summary of the variance analysis

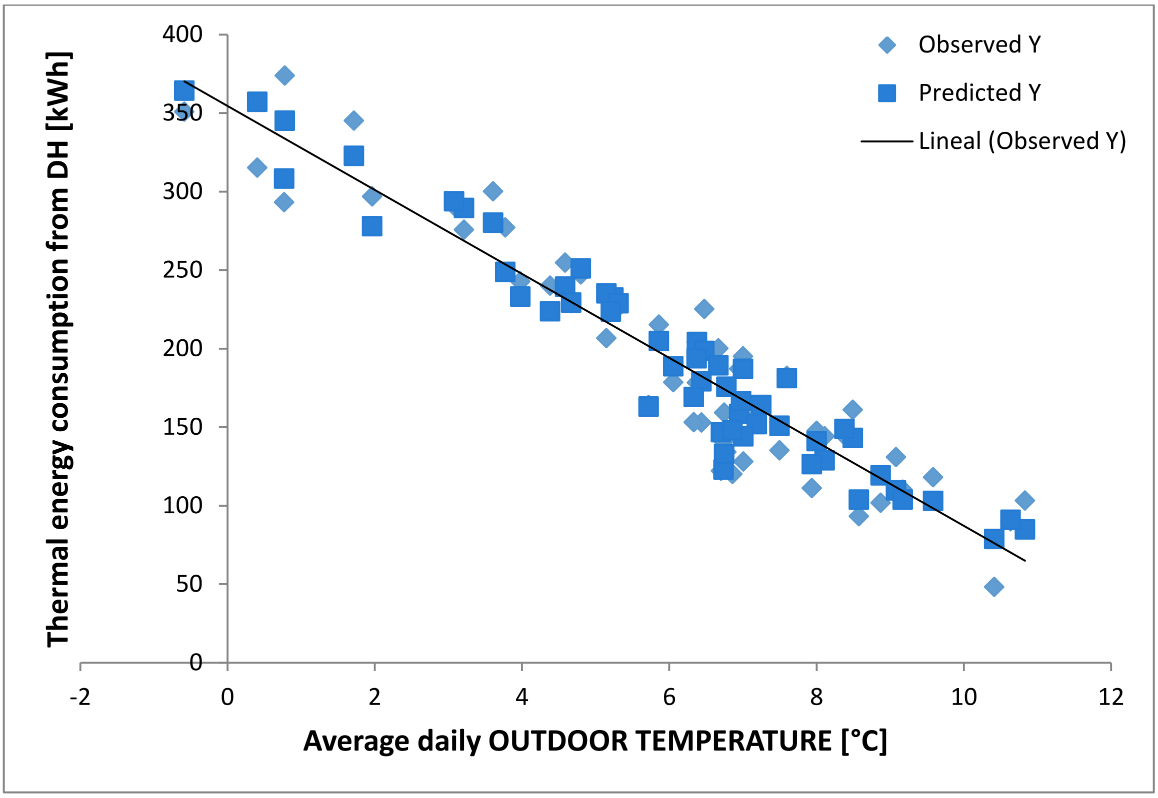

Figure 35: Adjusted regression curve with the outdoor temperature

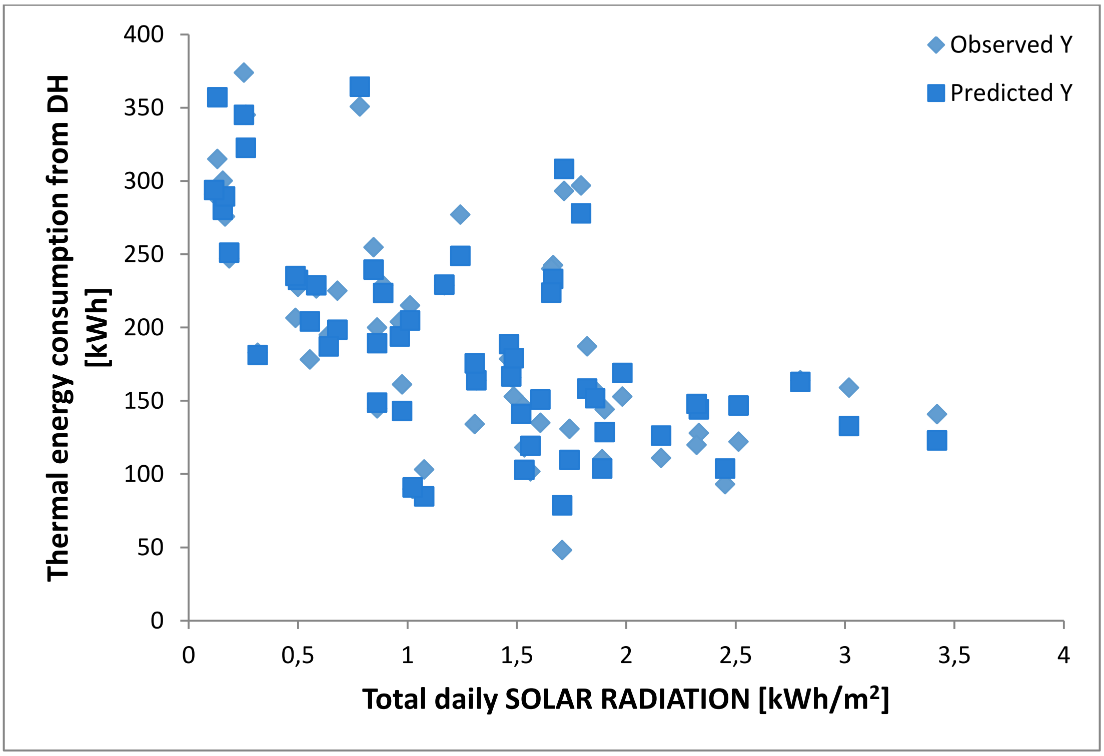

Figure 36: Adjusted regression curve with the solar radiation

The main conclusions that can be drawn from the regression analysis are the following ones:

- The obtained model combines two very important characteristics in the fields of energy modelling and regression analysis. First of all, its simplicity, in terms of functional form (linear) and number of independent variables (it only depends on two external conditions, including the Monday correction). Secondly, its accuracy, as the analysis of the statistic parameters shows that the model represents the problem under study very well.
- The sign of the coefficients for the outdoor temperature and the solar radiation is negative, which is consistent.
- In this case, the model does not predict negative values for Y (energy consumption) in any point of the range of values studied.
- The R^2 obtained in this regression analysis is 94%, which means that the model is very accurate and explains almost all the variability of the thermal energy consumption from the DH network in ZUB pilot building with the outdoor temperature and the solar radiation. This value is more than acceptable, as it far overcomes the minimum level recommended by the IPMVP methodology is 75%.
- The SE are low, t-statistic are very good and far greater than 2 for all the estimations in absolute value and p-values are almost null for all the independent variables (outdoor temperature and solar radiation), which mean that both variables are significant for the explanation of the energy consumption.

On the basis of the above, this model can be accepted and will be considered as the valid and the definitive one.

Decision making	
Decision	**TO ACCEPT THE MODEL AND CONSIDER IT AS VALID TO APPLY THE IPMVP FOR ZUB UC1**

Table 55: Summary of the modelling decision making for ZUB_Uc1

The next equation represents the ABE for the Uc1 in ZUB pilot buildings and will be used to evaluate the energy savings achieved, following the IPMVP guidelines.

$$H[kWh] = 370.08 - 23.82 \cdot T_{out}[^{o}C] - 25.32 \cdot Rad[kWh/m^2]$$

Equation 13: ZUB Building: Adjusted Baseline Energy

5 Sierra Elvira School Pilot Building

5.1 Description of the energy system

Sierra Elvira School (SES) is under a long term energy service contract with Veolia Company. The objective of this contract was to improve the energy performance of the generation system in the schools of Granada City. The payment terms of the contract was negotiated in order to amortize the required investment with a variable term depending on the energy demand of the buildings. It means that the return of investment made by the ESCO depends on the use of the installation and the comfort level of the end user.

The power of the generation system was dimensioning according to the reference provided by the tender specification accomplishing the technical requirement of each facility. The installation was based on a biomass boiler with two distribution circuits, one per zone. The refurbishment works carried out in the school in order to build a new library included a new circuit to provide thermal energy for this zone. The building envelope has a lack of insulation with original simple glass windows. This premises joined with the fact that the operating hours of the system are managed by the City Council and they have a planned budget to pay the heating services made that the facility cannot provide the necessary thermal energy to reach the required comfort level in the building.

The implementation of thermostatic valves in radiators with variable flow in the circuit does not work properly because there are no overheating zones. For these reason the main objective of the proposed use case (SES_Uc1) is to improve the comfort level of the users. The comfort level increases is been quantified with the indoor temperature sensor in order to compare with the baseline period. The IPMVP applied in this pilot deployed two different regression models with two dependent variables; energy and comfort, with the proposal of translate the comfort improvement in energy and economical savings.

5.2 IPMVP Specification

In the case of SES pilot building, "***Option C: Whole Facility***" has been selected to assess the energy savings obtained with the implementation of the different ECM that constitute the BaaS solution. As it was described in the previous document *"D6.3.1 Measure and Verification Plan"*, in this option of the IPMVP, the energy savings are calculated analysing the whole facility utility meter or sub-meter data using techniques from simple comparison of the energy consumptions to regression analysis, referencing these consumptions to external and internal conditions.

5.3 Measurement boundary

The following table defines the conditions of the evaluation process for CARTIF building.

Building	Measurement Boundary
SES Building	Biomass Consumption from biomass supplier. Electricity Consumption from electricity supplier.

Table 56: SES Building measurement boundary

Energy meters used to evaluate energy savings in SES Building are:

- B1: Biomass meter that measure energy consumption from biomass supplier.
- E1: Electrical meter that measure energy consumption from electrical network.

Applying the IPMVP Option C, the measures from B1 and E1 meters are needed to develop the model.

5.4 Baseline Period

The baseline period should represent all operating modes of the building. The length of the baseline period should be such that it contains all situations of building energy consumption. Each building has a different use and could have a different baseline period, where all energy profiles can be.

SES Building is a school building that has biomass-based heating system and is located in Granada (Spain). Energy consumption mainly depends on occupancy and weather. Heating season should be included within baseline period.

Taking into account both parameters (occupancy and weather) and ECM implementation plan, selected baseline period of SES Building is presented in the next table.

Start of baseline period	End of baseline period
1st October, 2013	31st March, 2015

Table 57: SES Building baseline period

Even though the heating season during winter periods is usually from October to April, the months of October, November and December were discarded in the regression analyses because there were a lot of inconsistent and non-representative data points.

5.5 Independent Variables

As it was mentioned before, energy consumption in SES Building mainly depends on external conditions and occupation, but also on building inertia, operational parameters and comfort level. The occupancy of the building, as well as the infiltrations, ventilation and internal loads are supposed to be uniform during the baseline period.

Independent Variables	Factor evaluated
Outdoor temperature (T_{out})	External conditions
Previous indoor temperature (T_{in-1})	Building inertia
Boiler return temperature (T_{ret})	Operation parameter
Indoor temperature (T_{in})	Comfort level

Table 58: SES Building independent variables

5.6 Static Factors

Static factors are those parameters that describe the installation and operation of the building and remain constant coinciding with baseline period, from energy consumption point of view. They include different types and some of the most important are the following ones:

- **Building characteristics** are assumed as constant during the evaluation period.
- **Equipment inventory** does not change during the evaluation period.
- **Occupancy** is assumed to be the same during the operation hours of the system.
- **Operating conditions**: operating period and season, schedules and set points.

For more details, all static factors considered for SES pilot building have been included in *Deliverable 6.1 Appendix E.*

5.7 Adjusted Baseline Energy for SES Building Use Case 1: Winter

SES Building Use Case (SES_Uc1) is defined in *Deliverable 5.1 "Building Services: Functional and interoperability requirements"*. The aim is to reduce the energy and electrical consumption associated to the distribution system according to demand installation and comfort constraints balancing the thermal comfort levels and the energy consumption of the complete system.

The proposed use case for this typology of buildings is to manage in the best way the heating system according to the real demand of the building. This use case is applicable to a large number of facilities that have the same structure for the district heating system that distributes thermal energy to secondary circuits. In this cases, the more usual operation of the heat generators are associated with the demand in any secondary circuit. The secondary circuits usually operate according to a set schedule of operation that is determined depending on the needs of the user, the weather conditions and the experience of personal and maintenance.

For this reason it is very common for heating times are scheduled so that all building spaces are desired comfort levels, which means that there are areas with overheating so other areas have the required levels of comfort.

After a comprehensive previous study aimed to understand the characteristics and operation of the energy system for the winter user case in SES pilot building, numerous regression analysis have been conducted trying to model the energy consumption during the winter period (focussing on the thermal energy) referencing it to different independent variables such as external conditions (outdoor temperature and solar radiation) and indoor conditions (indoor temperature). These models are based on the baseline data of the pilot building. This analysis requires a previous work to gather, process and discriminate the data measured and collected by the different sensors and meters that are implemented in the pilot building, in order to adequate them for the regression analysis purposes.

The first approach is to look for **linear regression models** for the energy consumption as a function of the outdoor temperature, indoor temperature, building and operation conditions, etc., due to its simplicity and the energy sense (easier to handle and interpret).

The regression analyses included in this section assume a **daily modelling** (each day represents a data point of the model) of the problem under study. In this modelling approach, those variables related to energies (thermal energy produced from biomass) should be included as the total daily consumption. On the other hand, other variables such as temperatures may be included as average or maximum daily temperature. This consideration has been taken based on the evidence that a building heating system is a very inertial system: the response of the energy system is not instantaneous, that is, the energy consumption has not an immediate effect in the heating of the building, and thus in the increase of the indoor temperature. It takes a certain time to heat the rooms inside the building.

On the one hand, the **daily energy consumption** (in MWh) is taken as the response variable in all the regression models that will be considered. The thermal energy meter does not measure the gas consumption directly, but it register the gas accumulated, storing the data of the accumulated energy consumption every 15 minutes. Therefore, the daily consumption is determined as the difference between the last and the first register of the day.

Finally, as it was previously mentioned, it should be numerous previous analyses were carried out in order to lead to the final models that are included in the following points of the present section.

5.7.1 Model 1

Independent variables

- Outdoor temperature (daily average)
- Boiler return temperature (daily average)
- Indoor temperature (daily maximum)

Modelling period

After a comprehensive study of the occupancy of the building and the weather conditions in the winter period, the timetables and bank holidays, profile and ranges of the variables under study, etc., the period that has been considered to develop the indoor comfort model is from January to March 2015.

Model	
Period	7th January 2015 – 27th March 2015
Frequency	Daily (a day corresponds to a point of the model)

Table 59: Modelling period and frequency

Model adjustment

The modelling strategy is to use multiple linear regression techniques to obtain a linear model that can predict the thermal energy consumption in SES building as function of the indoor temperature, the outdoor temperature and the boiler return temperature). This functional form (linear) is preferable due to its simplicity and the energy sense.

$$E[MWh] = a - b \cdot T_{out}[^{\circ}C] + c \cdot T_{ret}[^{\circ}C] - d \cdot T_{ind}[^{\circ}C]$$

Equation 14: Proposed model for the ABE in SES_Uc1 in the zone 1 of the building

Analysis of the results and conclusions

Regression statistics	
Coefficient of determination R^2	50%
Adjusted R^2	47%

Standard error SE	0.10
Number of observations	56

Table 60: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	0.19	0.18	1.07	0.291
b (Slope for the outdoor temperature)	-0.01	0.01	-1.20	0.236
c (Slope for the return temperature)	0.02	0.00	6.14	0.000
d (Slope for the indoor temperature)	-0.03	0.01	-2.20	0.032

Table 61: Summary of the variance analysis

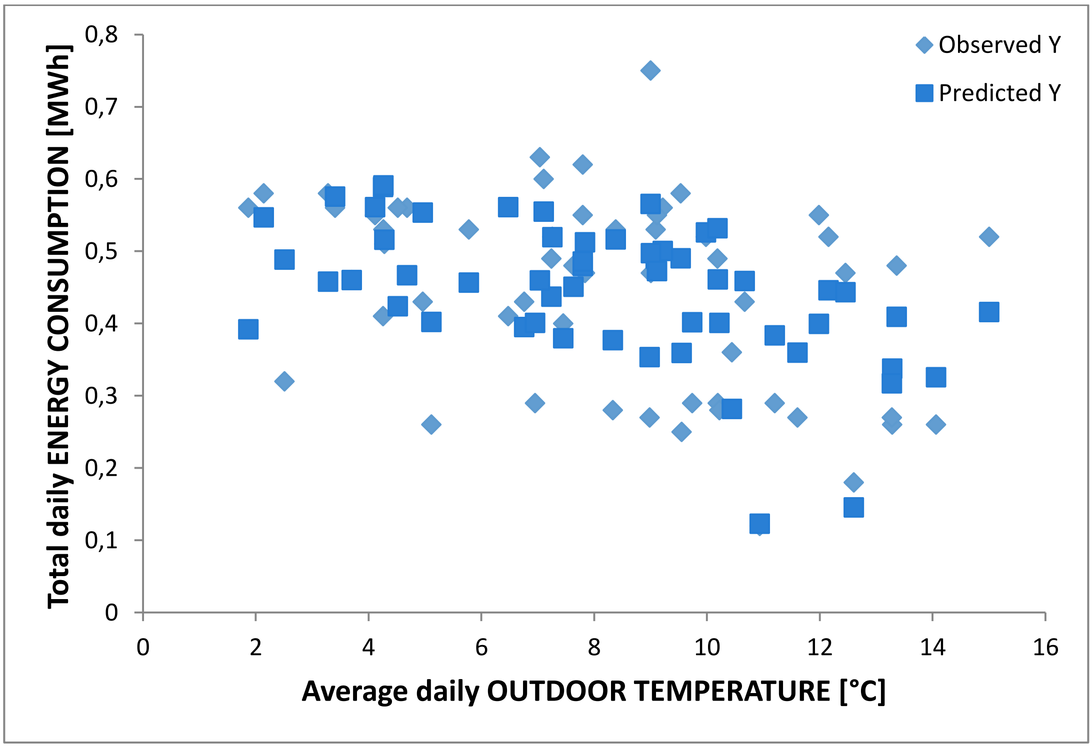

Figure 37: Adjusted regression curve with the outdoor temperature

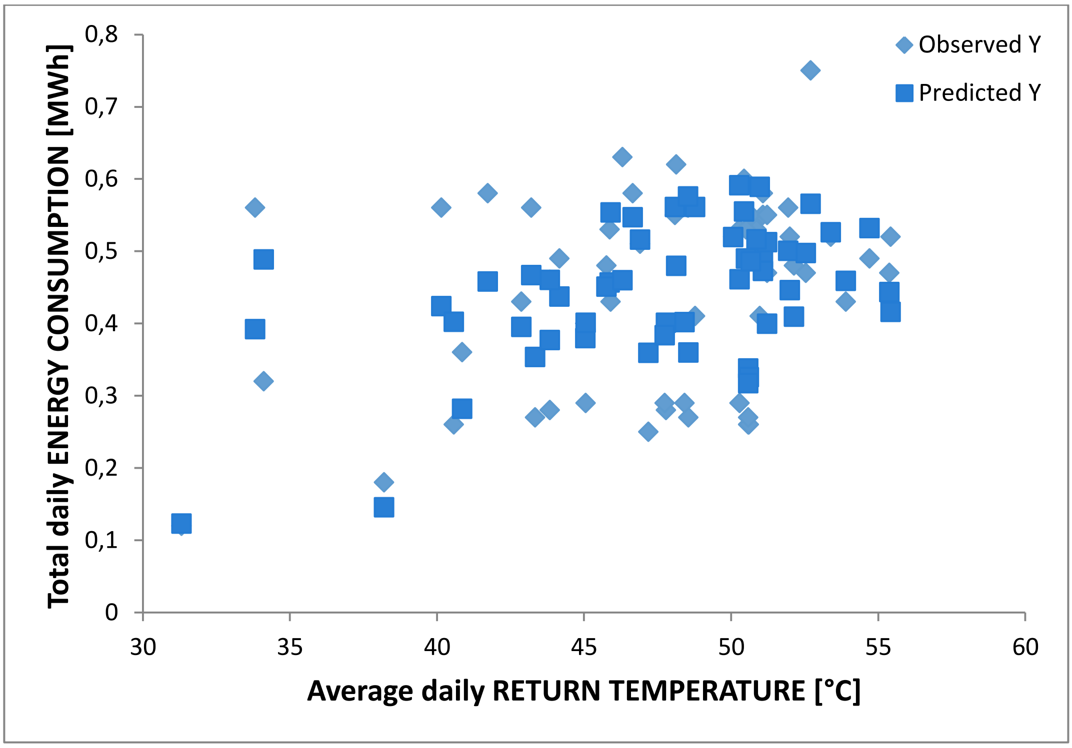

Figure 38: Adjusted regression curve with the return temperature

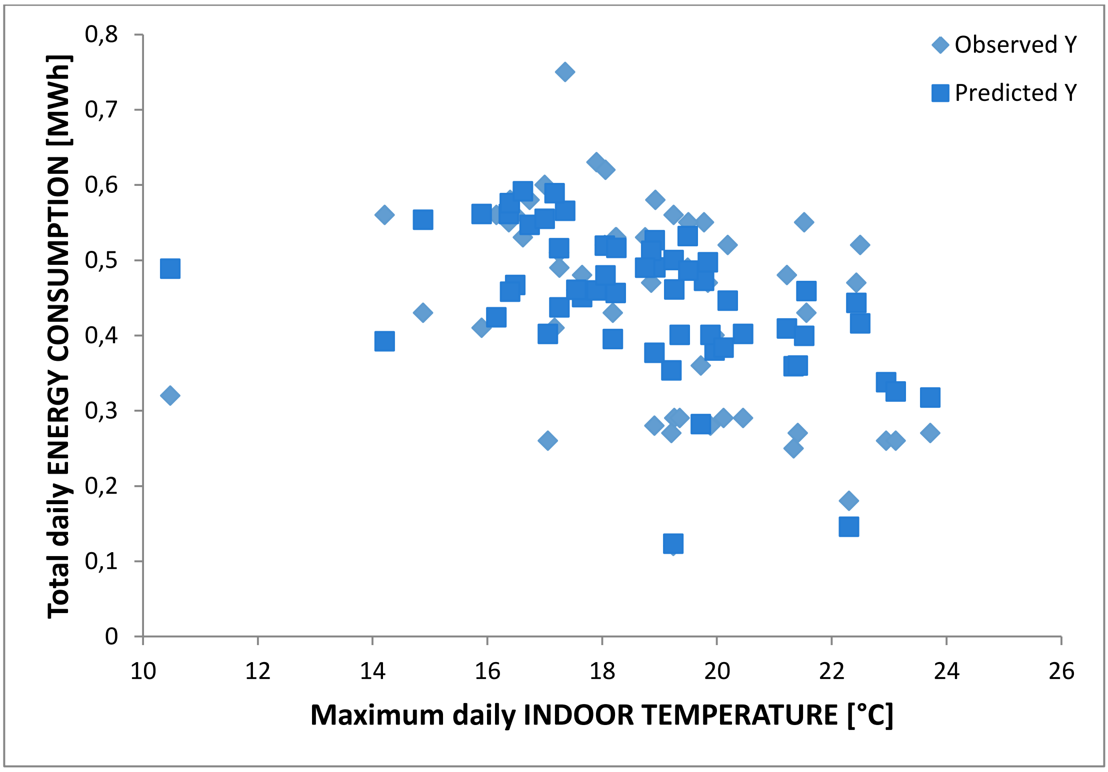

Figure 39: Adjusted regression curve with the indoor temperature

The main conclusions that can be drawn from the previous regression analysis are the following ones:

- The sign obtained for the outdoor temperature and the previous indoor temperature is the right one, but not for the indoor temperature.
- The model does not adjust well to the data points. The R^2 obtained in this regression analysis is 50%, which is very low for this kind of energy models (the minimum level recommended by the IPMVP methodology is 75%).

Therefore, this model has to be rejected. As the heating system in SES building is very inertial, the proposal for the next model is to include another variable that reflects this building inertia. To do that, it will be considered the previous indoor temperature (which is calculated as the average indoor temperature during the hour before switching on the heating system, which is programmed by a defined schedule).

Decision making	
Decision	**TO REJECT THE MODEL**
Change proposal	TO INCLUDE THE BUILDING INERTIA IN THE MODEL, AS THE INDOOR TEMPERATURE BEFORE THE HEATING SCHEDULE

Table 62: Summary of the modelling decision making for SES_Uc1

5.7.2 Model 2

Independent variables

- Outdoor temperature (daily average)
- Boiler return temperature (daily average)
- Previous Indoor temperature (daily average)
- Indoor temperature (daily maximum)

Modelling period

The same period than in Model 1 has been considered.

Model adjustment

The same mathematical expression has been considered, including the previous indoor temperature as an independent variable.

$$E[MWh] = a - b \cdot T_{out}[^{\circ}C] + c \cdot T_{ret}[^{\circ}C] - d \cdot T_{ind-1}[^{\circ}C] - e \cdot T_{ind}[^{\circ}C]$$

Equation 15: Proposed model for the ABE in SES_Uc1 in the zone 1 of the building

Analysis of the results and conclusions

Regression statistics

Coefficient of determination R^2	63%
Adjusted R^2	60%
Standard error SE	0.09
Number of observations	56

Table 63: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	-0.23	0.19	-1.22	0.228
b (Slope for the outdoor temperature)	-0.01	0.01	-1.95	0.056
c (Slope for the return temperature)	0.01	0.00	5.46	0.000
d (Slope for the previous indoor temperature)	-0.06	0.02	-4.16	0.000
e (Slope for the indoor temperature)	0.06	0.02	2.52	0.015

Table 64: Summary of the variance analysis

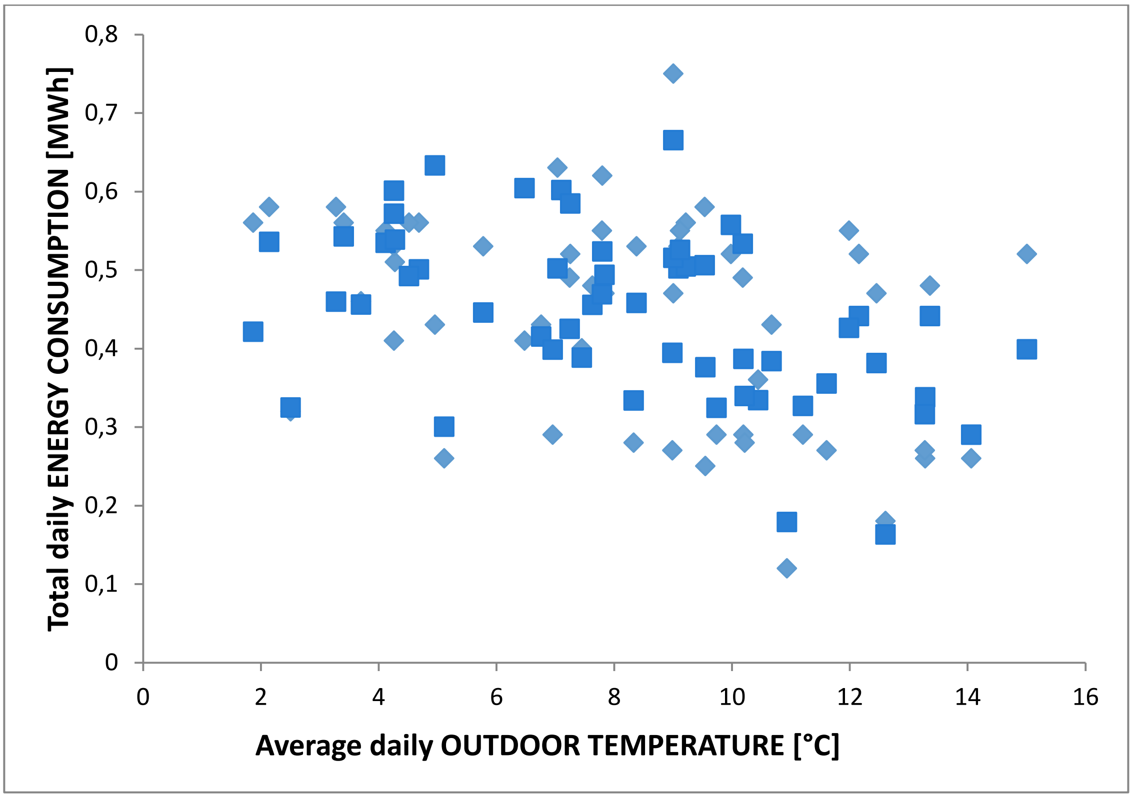

Figure 40: Adjusted regression curve with the outdoor temperature

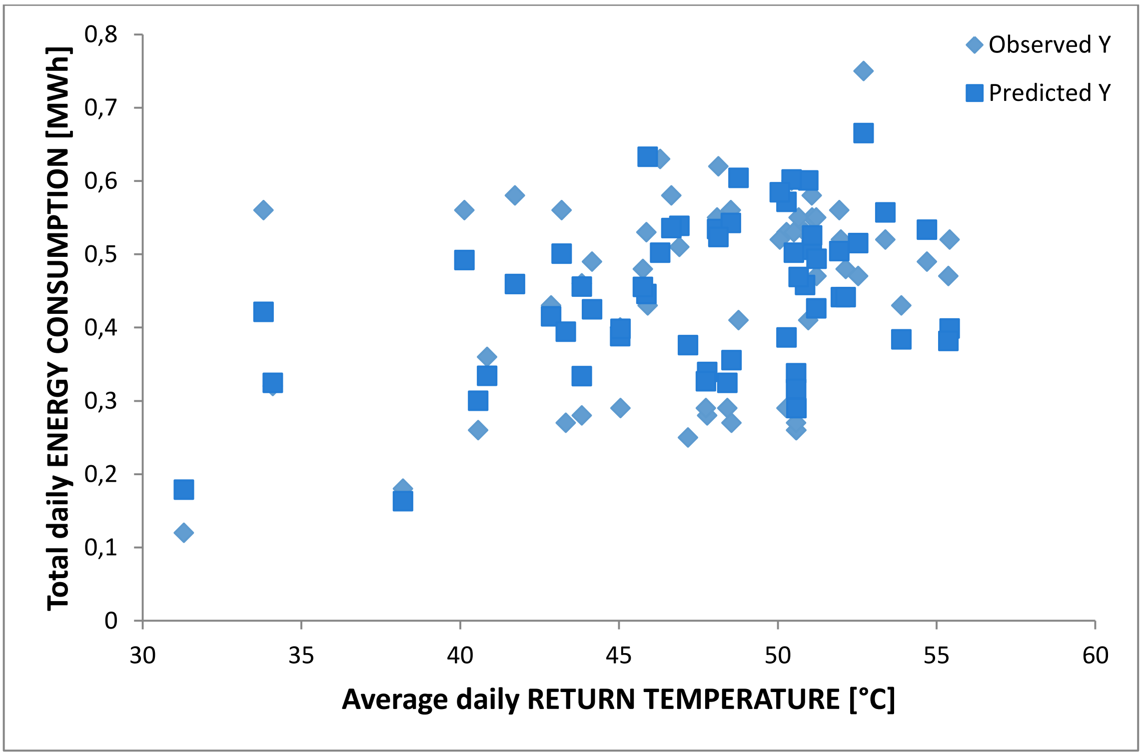

Figure 41: Adjusted regression curve with the return temperature

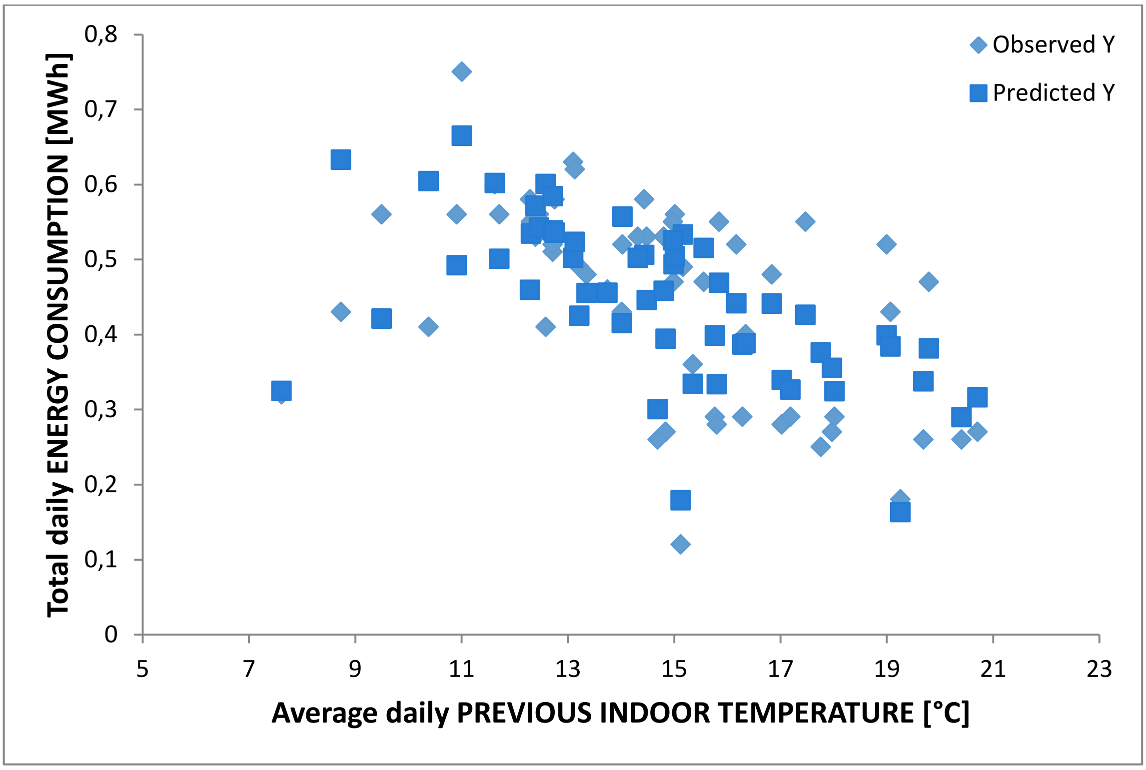

Figure 42: Adjusted regression curve with the previous indoor temperature

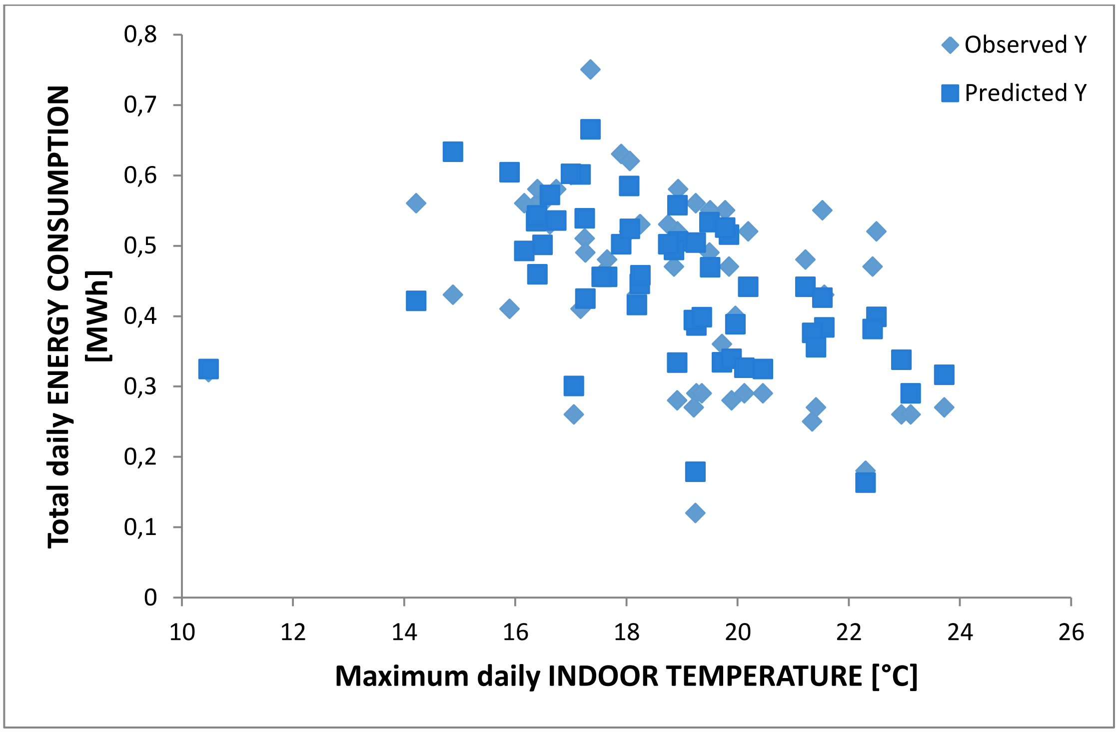

Figure 43: Adjusted regression curve with the indoor temperature

The main conclusions that can be drawn from the previous regression analysis are the following ones:

- The sign obtained for the outdoor temperature and the previous indoor temperature is the right one, but not for the indoor temperature.
- The R^2 obtained in this regression analysis is 63%, which is less than the minimum level recommended by the IPMVP methodology (75%).

Therefore, this model has to be rejected.

Decision making	
Decision	**TO REJECT THE MODEL**
Change proposal	FURTHER DATA EXPLORATION

Table 65: Summary of the modelling decision making for SES_Uc1

5.7.3 Model 3

Independent variables

- Outdoor temperature (daily average)
- Boiler return temperature (daily average)
- Previous Indoor temperature (daily average)
- Indoor temperature (daily maximum)

After exploring the data more in detail, it can be observed that the energy consumption on Mondays has a different profile than the all other days of the week. Therefore this aspect should be included in the model. Typically this can be done including a qualitative variable that takes the value 1 when it is Monday and 0 in all other cases. In fact, this modification does not increase the complexity of the model: it is just a correction of the intercept, keeping the slopes or quantitative coefficient constant.

Modelling period

The same period than in Model 1 has been considered.

Model adjustment

It has been considered the same mathematical expression than in the previous model (linear regression). The only change is the Monday correction for the intercept.

Analysis of the results and conclusions

Regression statistics	
Coefficient of determination R^2	68%

Adjusted R^2	65%
Standard error SE	0.08
Number of observations	56

Table 66: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	-0.19	0.18	-1.05	0.299
b (Slope for the outdoor temperature)	-0.01	0.01	-1.68	0.099
c (Slope for the return temperature)	0.02	0.00	6.40	0.000
d (Slope for the previous indoor temperature)	-0.05	0.02	-2.89	0.006
e (Slope for the indoor temperature)	0.03	0.02	1.42	0.160
f (Mondays correction)	0.09	0.03	2.82	0.007

Table 67: Summary of the variance analysis

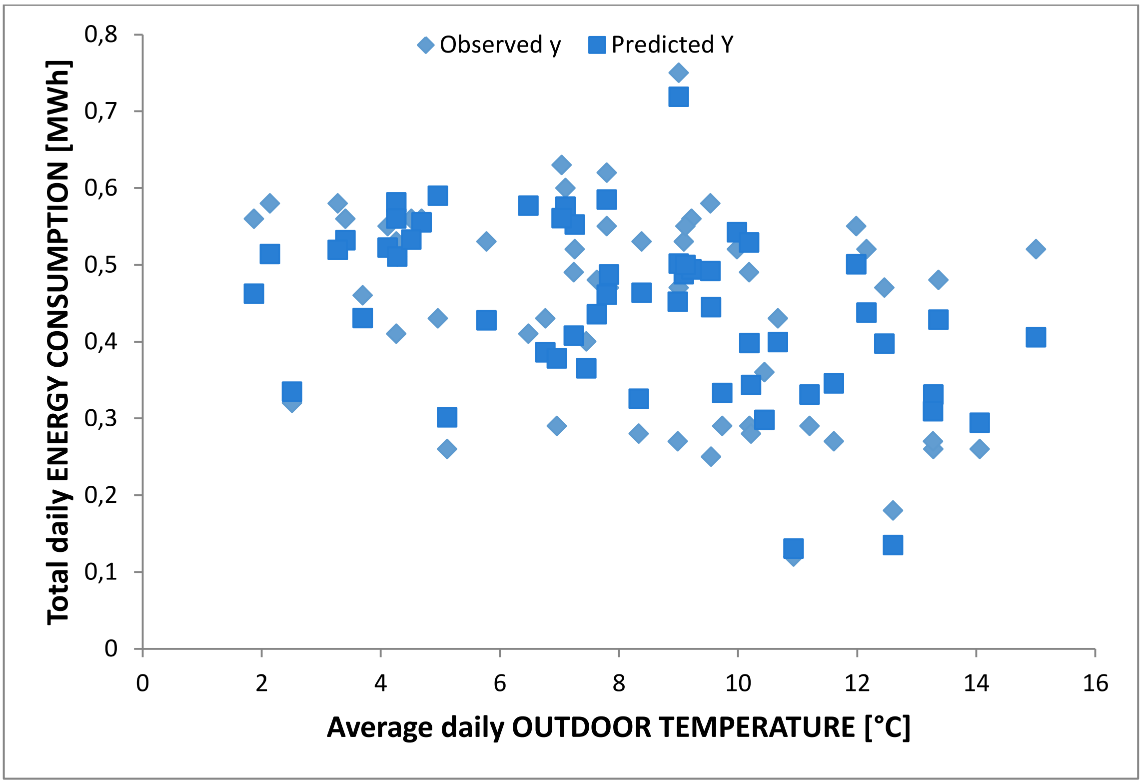

Figure 44: Adjusted regression curve with the outdoor temperature

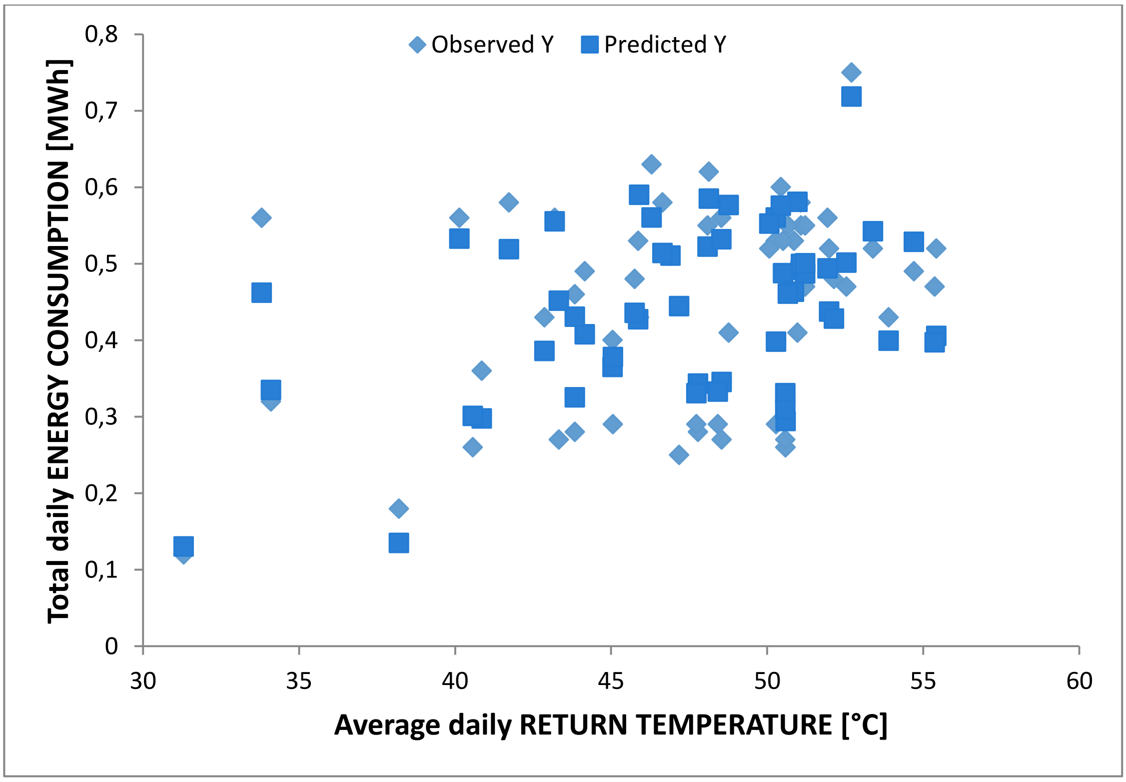

Figure 45: Adjusted regression curve with the return temperature

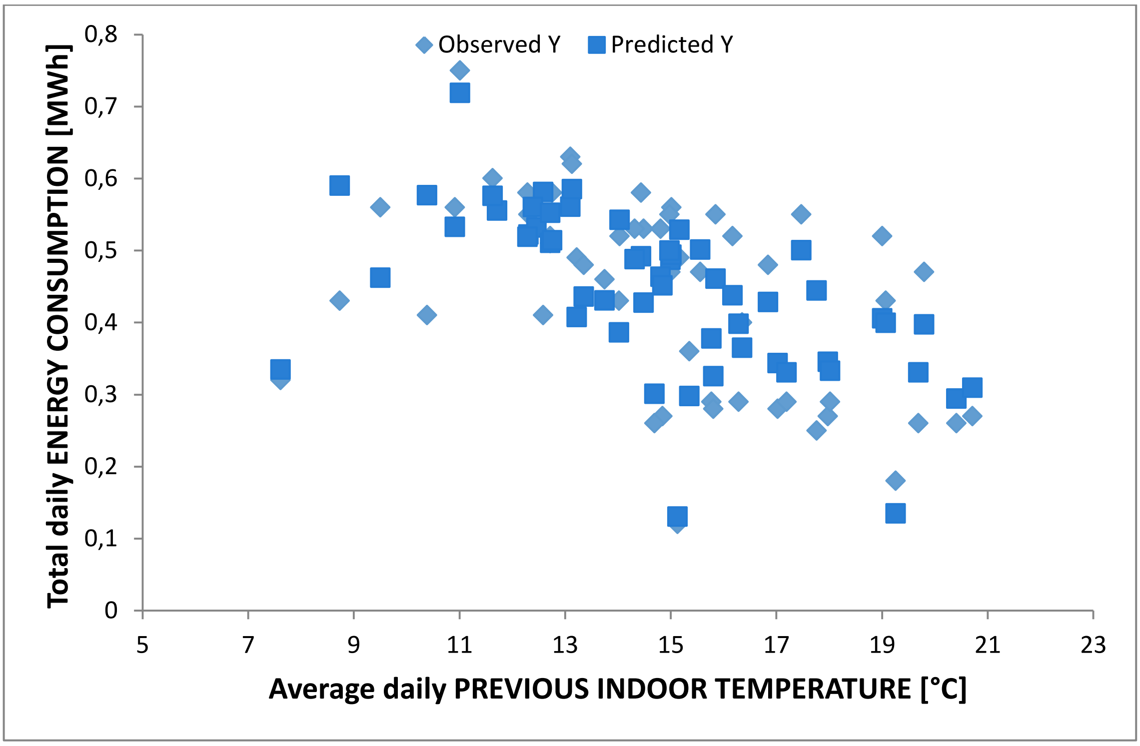

Figure 46: Adjusted regression curve with the previous indoor temperature

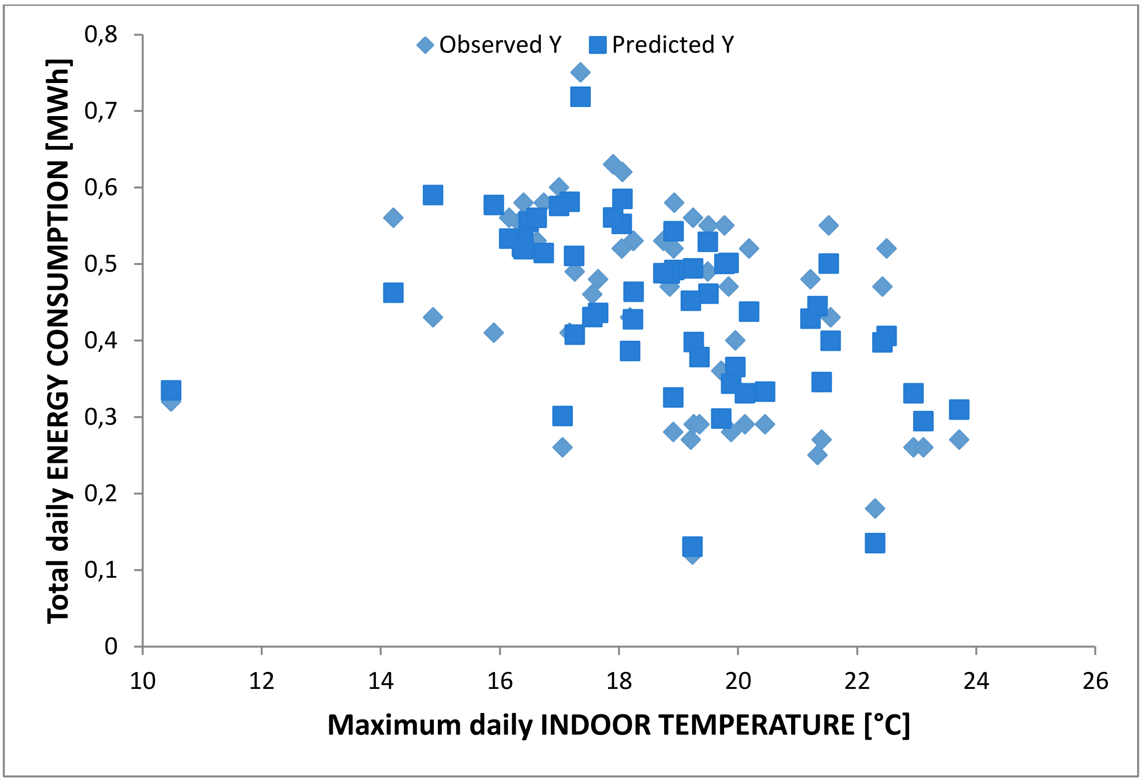

Figure 47: Adjusted regression curve with the indoor temperature

The main conclusions that can be drawn from the previous regression analysis are the following ones:

- The sign obtained for the outdoor temperature and the previous indoor temperature is the right one, but not for the indoor temperature.
- The model is more accurate than the previous one, as it adjust better to the data points. However it is not good enough to be accepted according to IPMVP recommendations: the R^2 obtained in this regression analysis is 68%, which is less than the minimum level recommended by the IPMVP methodology (75%).

Therefore, this model has to be rejected.

Decision making	
Decision	**TO REJECT THE MODEL**
Change proposal	FURTHER DATA EXPLORATION

Table 68: Summary of the modelling decision making for SES_Uc1

5.7.4 SES Building ABE Final Model

Independent variables

- Outdoor temperature (daily average)
- Boiler return temperature (daily average)
- Previous Indoor temperature (daily average)
- Indoor temperature (daily maximum)

After exploring the data more in detail, in addition to the Monday correction, it is observed that the Month to which correspond the different data points may have an influence on the thermal energy consumption. For this reason, it is proposed to include a qualitative variable that takes the value 1 when it is January and 0 in all other cases. In fact, this modification does not increase the complexity of the model: it is just a correction of the intercept, keeping the slopes or quantitative coefficient constant.

Modelling period

The modelling period is the same than in the previous analyses.

Model adjustment

The modelling strategy and the mathematical expression is the same than in the previous analysis, with the only change on the month correction.

Analysis of the results and conclusions

Regression statistics

Coefficient of determination R^2	76%
Adjusted R^2	73%
Standard error SE	0.07
Number of observations	56

Table 69: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	-0.10	0.16	-0.60	0.5532
b (Slope for the outdoor temperature)	-0.01	0.01	-0.80	0.4298
c (Slope for the return temperature)	0.01	0.00	5.58	0.0000
d (Slope for the previous indoor temperature)	-0.02	0.02	-1.02	0.3132
e (Slope for the indoor temperature)	0.01	0.02	0.54	0.5905
f (Mondays correction)	0.12	0.03	4.06	0.0002
d (March correction)	-0.13	0.03	-3.89	0.0003

Table 70: Summary of the variance analysis

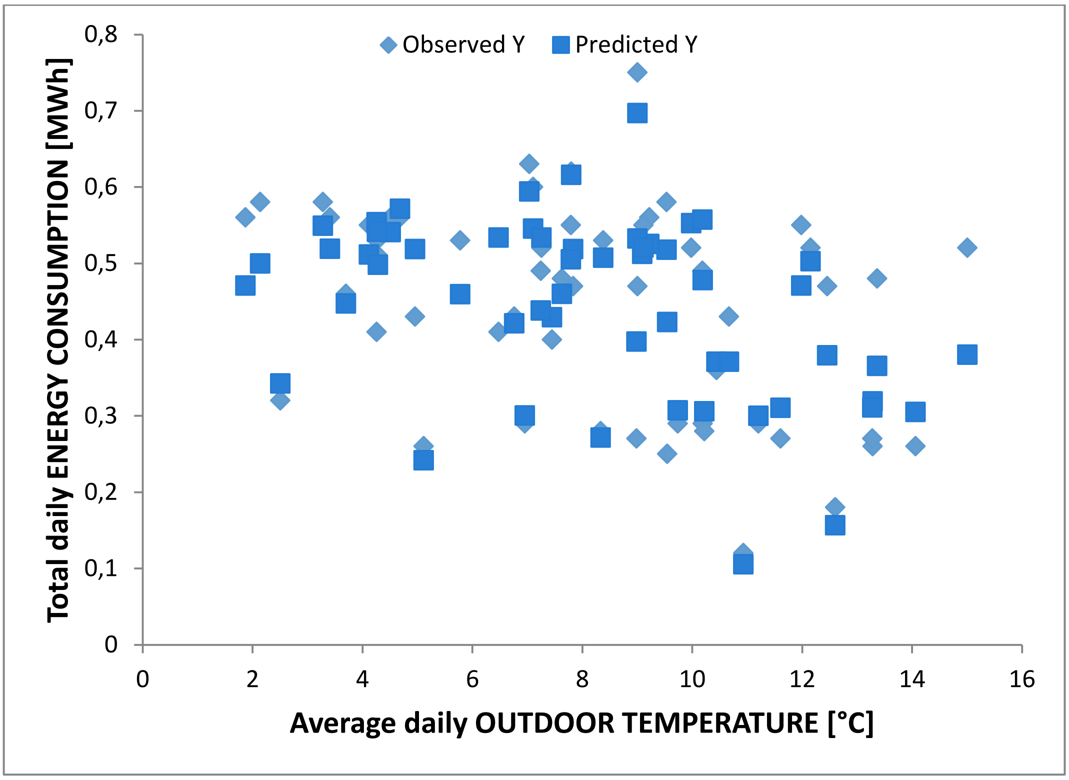

Figure 48: Adjusted regression curve with the outdoor temperature

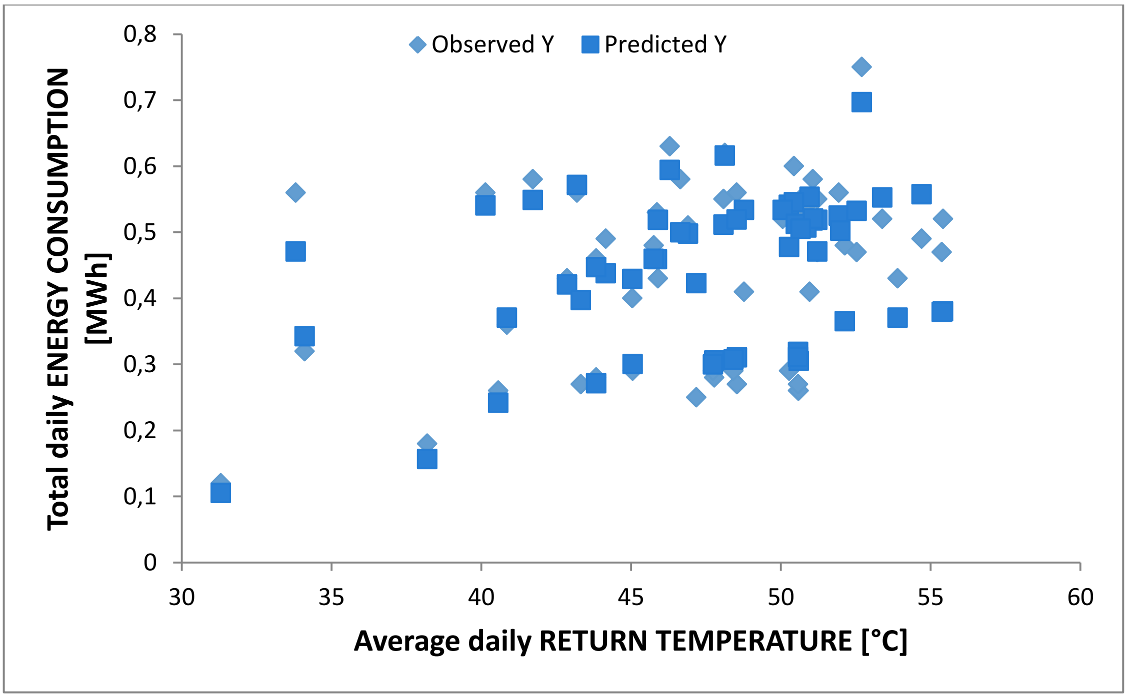

Figure 49: Adjusted regression curve with the return temperature

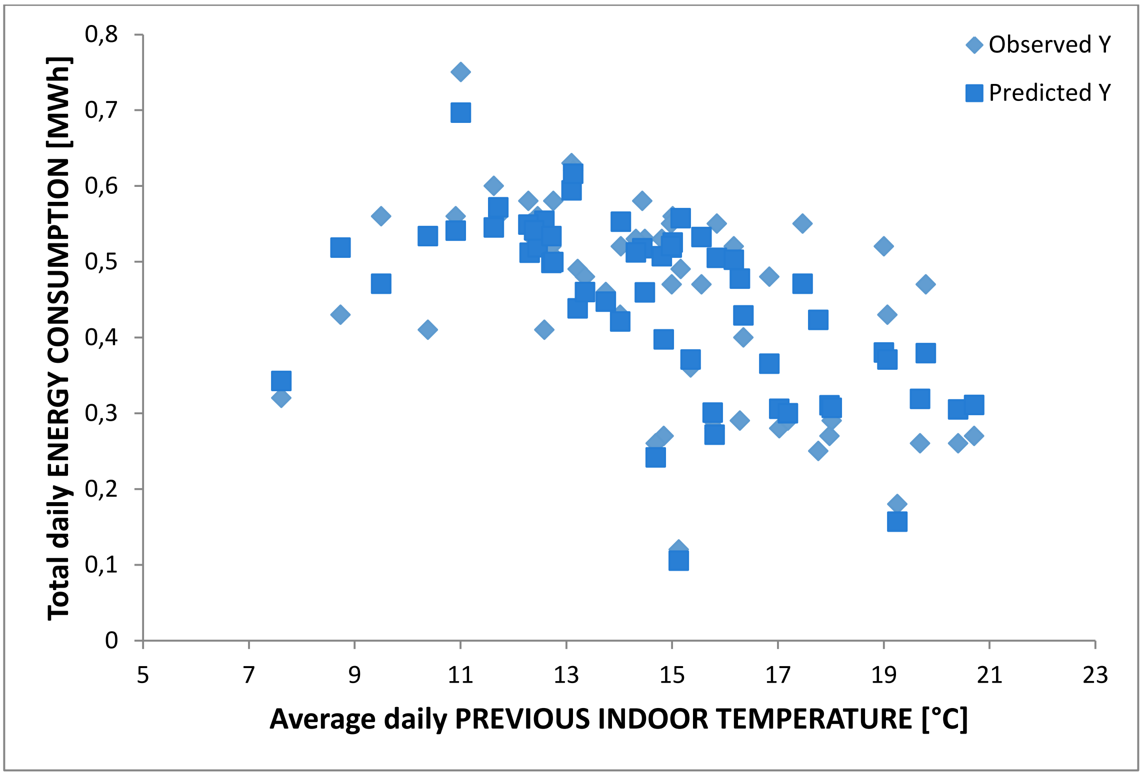

Figure 50: Adjusted regression curve with the previous indoor temperature

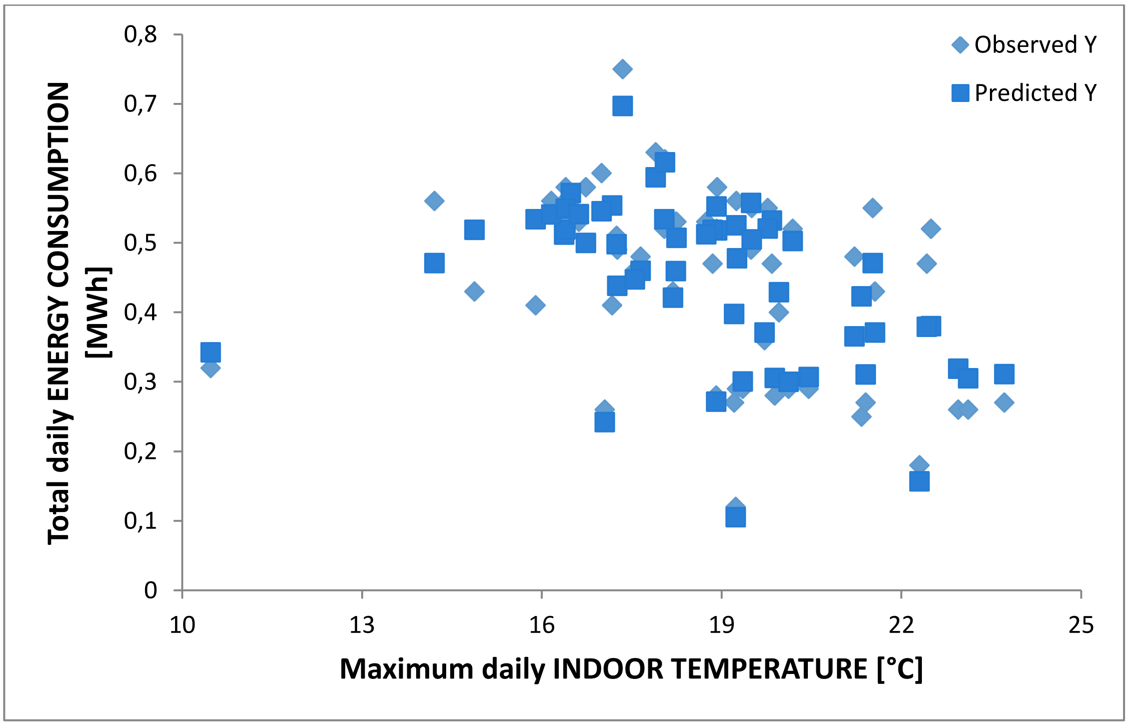

Figure 51: Adjusted regression curve with the indoor temperature

The main conclusions that can be drawn from the previous regression analysis are the following ones:

- The sign obtained for the outdoor temperature and the previous indoor temperature is the right one, but not for the indoor temperature.
- The model adjusts much better to the data points than the previous ones. The R^2 is 76%, which meets the IPMVP recommendations for this kind of models.

This model will be considered as the definitive one. Higher accuracy would be desirable but at this point this model will be considered as acceptable, taking into account the thermal ineffiencies of the building and the problems of the energy systems to reach a good comfort level in the different rooms.

Decision making	
Decision	**TO ACCEPT THE MODEL AND USE IT TO EVALUATE THE ECM IN SES_UC1, FOLLOWING THE IPMVP**

Table 71: Summary of the modelling decision making for SES_Uc1

The next equation represents the ABE for the Uc1 in SES pilot buildings and will be used to evaluate the energy savings achieved, following the IPMVP guidelines. The qualitative variables “Day” and “Month” take the value 1 when it is Monday and March, respectively, and 0 in all other cases.

$$E = -0.10 - 0.01 \cdot T_{out} + 0.01 \cdot T_{ret} - 0.02 \cdot T_{in-1} + 0.01 \cdot T_{in} + 0.12 \cdot Day_{Monday} - 0.13 \cdot Month_{March}$$

Equation 16: SES Building: Adjusted Baseline Energy for Uc1

5.8 Thermal comfort model for SES pilot building

In addition to energy savings, the improvement of the thermal comfort inside of the SES pilot building is one of the main goals of BaaS project.

Numerous studies have been conducted in order to characterize the thermal comfort in SES building, analysing the data of indoor temperatures registered with the different sensors that are implemented in different rooms of the building. Next graph shows the temporal profile of the indoor temperature compared with the outdoor temperature (both in average) and the desired comfort level (e.g. 21ºC).

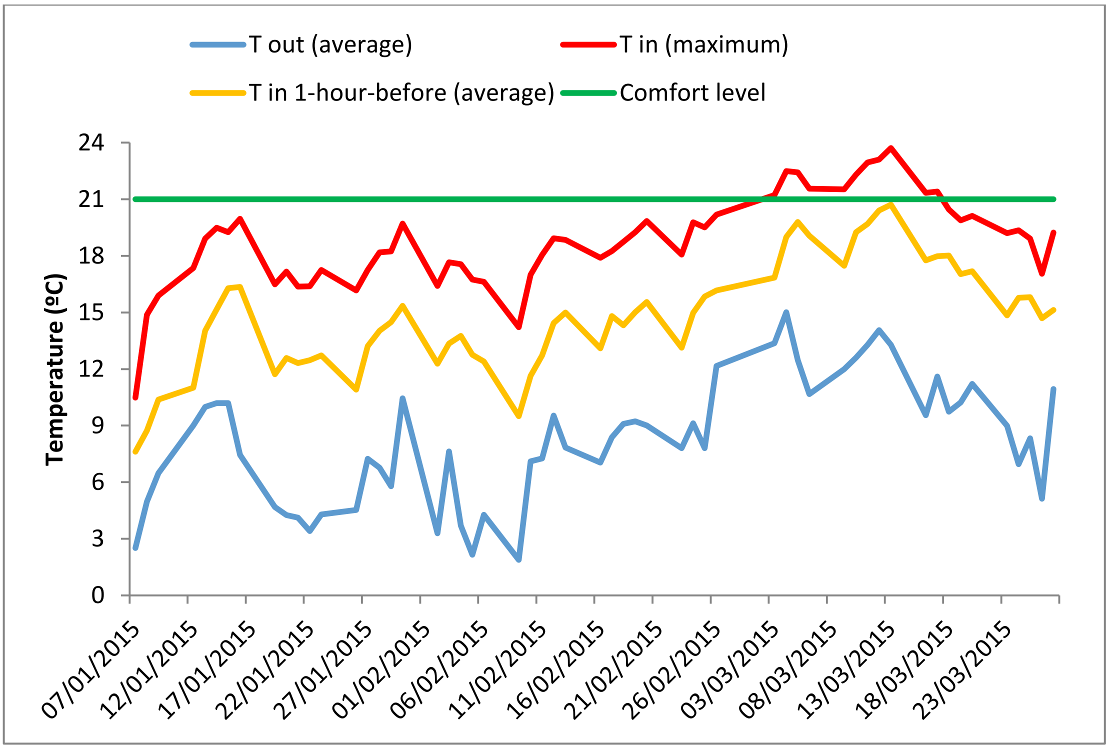

Figure 52: Indoor temperatures profile during the modelling period

The average indoor temperature level before turning on the heating is 14.8°C (calculated as the average temperature of the four 15 min-points in the period 5 – 6 am).

The maximum indoor temperature level reached during the hours of operation is, in average, 18.8°C. This is a quite low value and it means that an appropriate comfort (21°C) level is not reached at all most of the days, which implies that, with the current hours of operation, the system is not able to cover the thermal demand of the SES building. This is the reason that the regression model obtained for SES is less accurate than in the cases of CARTIF and ZUB pilot buildings. The energy consumption is not well-adjusted to the thermal demand, and hence, the energy consumption seems has not the high correlation that would be expected, with the outdoor temperature and the solar radiation. If the thermal energy generation were better adjusted to the real energy demand of the building, a proper and more accurate regression model could be obtained.

If the comfort level is not reached with the current operation mode, it means that more energy should be produced, and therefore, more biomass has to be consumed, which would increase the generation costs. Moreover, the main goal of BaaS project is to get energy savings with the energy conservation measures implemented in the installation. Nevertheless, this conclusion of increasing the energy consumption seems to be against it because instead of savings more energy is consumed. If we wanted to reach the comfort level without the implementation of the BaaS solution (i.e. with the original situation of SES), the primary energy consumption increase would be even higher. Therefore, the energy savings have to be evaluated comparing the energy consumption that would be necessary to reach the comfort level with and without the BaaS project implementation. Next graph is a visual example of this concept.

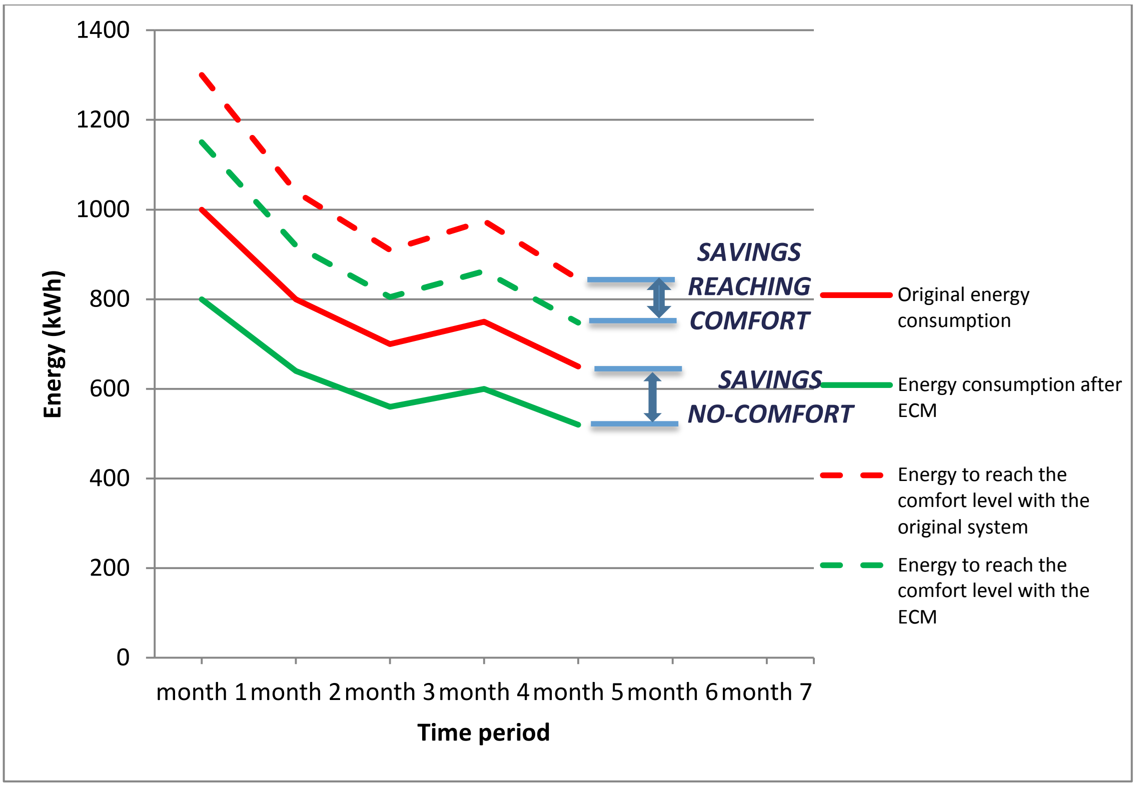

Figure 53: Combined objective of energy savings and comfort increase

Therefore, in conclusion, to reach the comfort level we need to increase the biomass (energy) consumption (compared to the original situation, in which the comfort level was not reached either). In order to reach the comfort level with the original system, the energy consumption would be higher. Therefore, the evaluation of the energy savings should be conducted comparing the energy consumption necessary to reach the comfort level without and with the implementation of the BaaS project.

5.8.1 Comfort level model for SES_Zone 1

Independent variables

- **Energy consumption** [MWh]: Total daily energy consumption. The data are obtained from the registers (every 1 minute) of the thermal energy meter installed in the zone 1.
- **Outdoor temperature** [°C]: Average daily outdoor temperature obtained from the data registered by the weather station every 15 minutes.
- **Previous indoor temperature** [ºC]: Average temperature during the previous hour before switching on the heating system.

Modelling period

After a comprehensive study of the occupancy of the building and the weather conditions in the winter period, the timetables and bank holidays, profile and ranges of the variables under study, etc., the period that has been considered to develop the indoor comfort model is from January to March 2015.

Model	
Period	7th January 2015 – 27th March 2015
Frequency	Daily (a day corresponds to a point of the model)

Table 72: Modelling period and frequency

Date	T_{ind} [°C]	E [kWh]	T_{out} [°C]	T_{ind-1} [°C]
07/01/2015	10.48	0.32	2.51	7.62
08/01/2015	14.88	0.43	4.96	8.74
09/01/2015	15.90	0.41	6.48	10.39
12/01/2015	17.36	0.75	9.00	11.01
13/01/2015	18.92	0.52	9.99	14.03
14/01/2015	19.50	0.49	10.19	15.17
15/01/2015	19.26	0.29	10.19	16.29
16/01/2015	19.96	0.40	7.45	16.35
19/01/2015	16.49	0.56	4.69	11.72
20/01/2015	17.18	0.41	4.26	12.59
21/01/2015	16.38	0.55	4.12	12.31
22/01/2015	16.40	0.56	3.41	12.46
23/01/2015	17.25	0.51	4.28	12.72
26/01/2015	16.16	0.56	4.52	10.91
27/01/2015	17.26	0.49	7.25	13.22
28/01/2015	18.19	0.43	6.76	14.02

29/01/2015	18.24	0.53	5.78	14.49
30/01/2015	19.72	0.36	10.45	15.35
02/02/2015	16.40	0.58	3.28	12.29
03/02/2015	17.66	0.48	7.63	13.36
04/02/2015	17.56	0.46	3.70	13.75
05/02/2015	16.74	0.58	2.14	12.76
06/02/2015	16.62	0.53	4.27	12.40
09/02/2015	14.22	0.56	1.87	9.50
10/02/2015	17.00	0.60	7.11	11.63
11/02/2015	18.05	0.52	7.26	12.72
12/02/2015	18.93	0.58	9.54	14.44
13/02/2015	18.86	0.47	7.84	15.00
16/02/2015	17.91	0.63	7.04	13.10
17/02/2015	18.25	0.53	8.38	14.81
18/02/2015	18.75	0.53	9.09	14.32
19/02/2015	19.25	0.56	9.22	15.02
20/02/2015	19.85	0.47	9.01	15.56
23/02/2015	18.06	0.62	7.80	13.13
24/02/2015	19.78	0.55	9.12	14.98
25/02/2015	19.51	0.55	7.80	15.85
26/02/2015	20.19	0.52	12.16	16.17
03/03/2015	21.22	0.48	13.37	16.84
04/03/2015	22.50	0.52	15.01	19.00
05/03/2015	22.43	0.47	12.46	19.80
06/03/2015	21.56	0.43	10.67	19.07

09/03/2015	21.53	0.55	11.99	17.47
10/03/2015	22.31	0.18	12.61	19.26
11/03/2015	22.95	0.26	13.28	19.69
12/03/2015	23.12	0.26	14.06	20.41
13/03/2015	23.72	0.27	13.28	20.71
16/03/2015	21.34	0.25	9.55	17.77
17/03/2015	21.41	0.27	11.61	17.98
18/03/2015	20.46	0.29	9.74	18.02
19/03/2015	19.89	0.28	10.22	17.03
20/03/2015	20.12	0.29	11.21	17.19
23/03/2015	19.21	0.27	8.99	14.85
24/03/2015	19.36	0.29	6.96	15.77
25/03/2015	18.92	0.28	8.33	15.81
26/03/2015	17.06	0.26	5.12	14.70
27/03/2015	19.24	0.12	10.94	15.13

Table 73: Data summary of the modelling period

Model adjustment

The modelling strategy is to use multiple linear regression techniques to obtain a linear model that can evaluate the comfort level, predicting the indoor temperature that will be achieved in the building as function of the energy consumption, the outdoor temperature and the building inertia (using the previous indoor temperature, when the heating system is switched on every day).

The coefficients obtained for the three independent variables should be positive, as they make that the indoor temperature increases.

$$T_{ind}[^{o}C] = a + b \cdot E[MWh] + c \cdot T_{out}[^{o}C] + d \cdot T_{ind\_prev}[^{o}C]$$

Equation 17: Proposed comfort model for the Uc1 of SES pilot building in Zone 1

Analysis of the results and conclusions

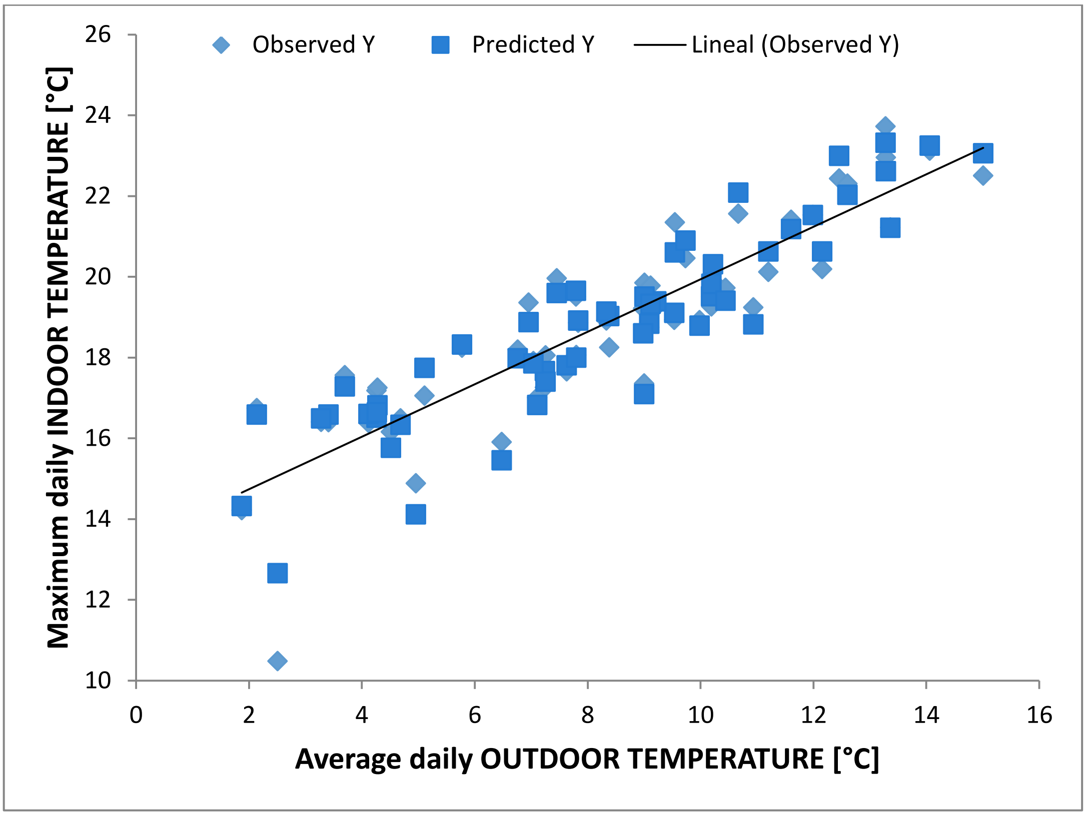

Figure 54: Adjusted regression curve with the outdoor temperature

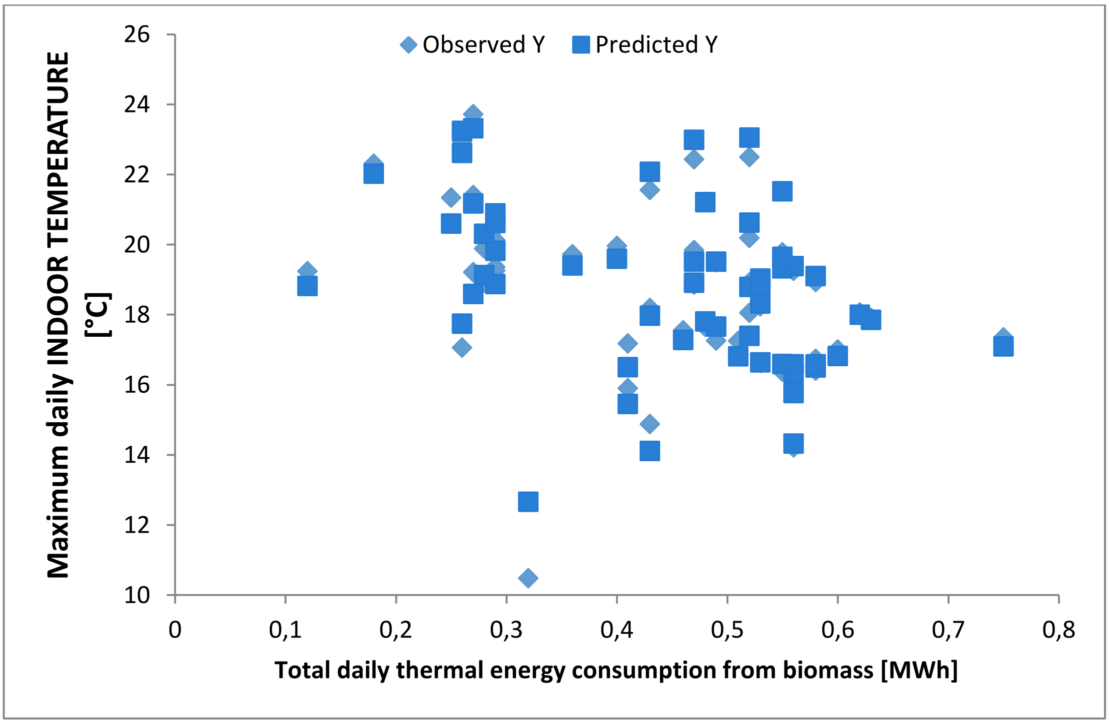

Figure 55: Adjusted regression curve with the energy consumption

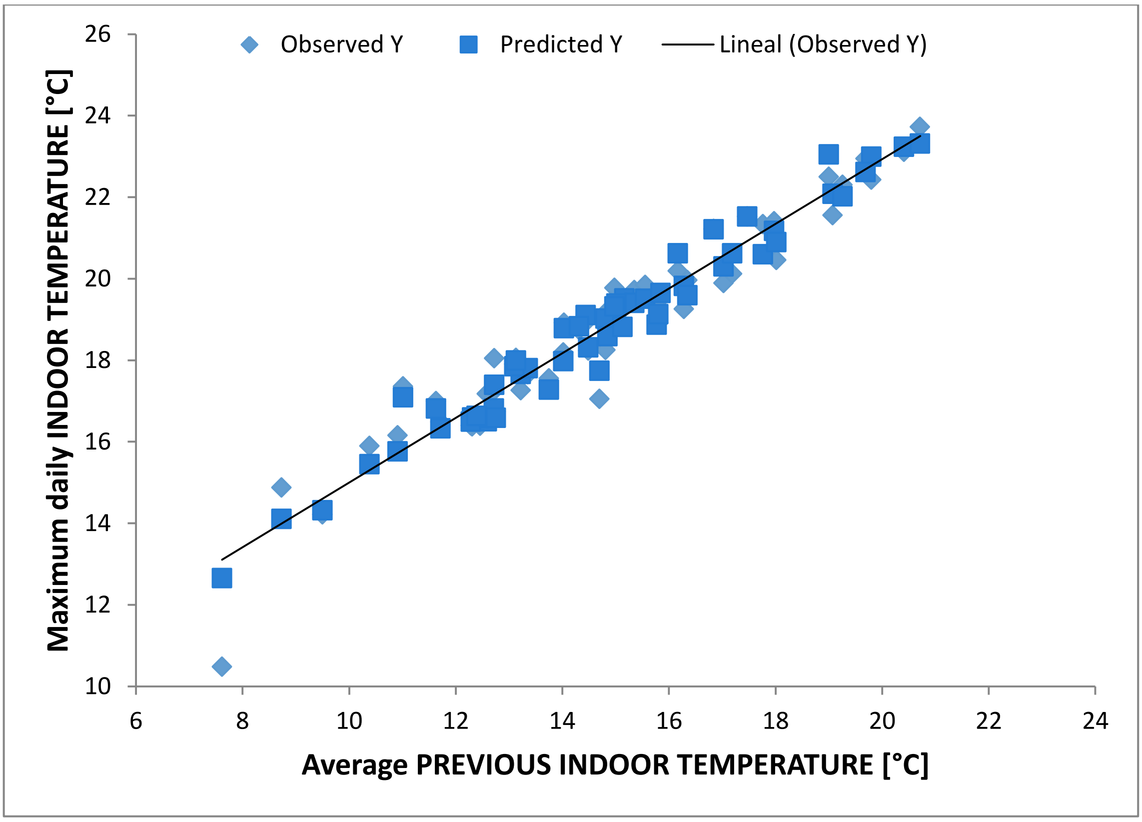

Figure 56: Adjusted regression curve with the outdoor temperature

Regression statistics	
Coefficient of determination R^2	96%
Adjusted R^2	96%
Standard error SE	0.50
Number of observations	56

Table 74: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	6.41	0.65	10.44	0.00
b (Slope for the energy consumption)	2.19	0.13	3.82	0.00

c (Slope for the outdoor temperature)	0.19	0.23	5.13	0.00
d (Slope for the previous indoor temperature)	0.67	0.04	15.08	0.00

Table 75: Summary of the variance analysis

The main conclusions that can be drawn for this regression analysis are the listed below:

- All the independent variables considered in the model to explain the indoor temperature are significant, being the previous indoor temperature (building inertia) and the outdoor temperature (weather conditions) the two with a higher influence in the regression. This can be due to the fact that the heating system does not meet the energy needs of the SES building, and thus, it cannot overcome the external and internal thermal conditions.
- The coefficients obtained for the three variables are consistent (positive).
- Regarding the statistic parameters, the R^2 is very high (96%) which means that the model explains almost all the variability of the data points studied. The t-statistics are good in all cases and the p-values are zero, which means that all the variables included in the model are significant.

On the basis of the conclusions above, this model for the thermal comfort level is very consistent and accurate and therefore it can be accepted. During the reporting period it will be used to evaluate the comfort improvements achieved with the implementation of the BaaS solution.

Decision making	
Decision	**TO ACCEPT THIS MODEL AND USE IT TO ASSESS THE COMFORT IMPROVEMENTS IN SES BUILDING_ZONE 1**

Table 76: Summary of the modelling decision making

The next equations represent the model to evaluate the comfort improvements obtained with the SES Uc1 in the zone 1 of the building.

$$T_{ind}[^{\circ}C] = 6.41 + 2.19 \cdot E[MWh] + 0.19 \cdot T_{out}[^{\circ}C] + 0.67 \cdot T_{ind\_prev}[^{\circ}C]$$

Equation 18: SES Building indoor comfort model for Zone 1

5.8.2 Comfort level model for SES_Zone 2

Independent variables

- **Energy consumption** [MWh]: Total daily energy consumption. The data are obtained from the registers (every 1 minute) of the thermal energy meter installed in the zone 1.
- **Outdoor temperature** [°C]: Average daily outdoor temperature obtained from the data registered by the weather station every 15 minutes.
- **Previous indoor temperature** [ºC]:

Modelling period

After a comprehensive study of the occupancy of the building and the weather conditions in the winter period, the timetables and bank holidays, profile and ranges of the variables under study, etc., the period that has been considered to develop the indoor comfort model is from January to March 2015.

Model	
Period	7th January 2015 – 27th March 2015
Frequency	Daily (a day corresponds to a point of the model)

Table 77: Modelling period and frequency

Date	T_{ind} [°C]	E [kWh]	T_{out} [°C]	T_{ind-1} [°C]
07/01/2015	11.81	0.34	2.51	8.47
08/01/2015	16.03	0.45	4.96	9.61
09/01/2015	17.03	0.46	6.48	11.23
12/01/2015	18.20	0.75	9.00	11.97
13/01/2015	19.89	0.45	9.99	14.44
14/01/2015	20.66	0.47	10.19	15.87
15/01/2015	21.24	0.28	10.19	16.93
16/01/2015	20.53	0.39	7.45	17.00
19/01/2015	17.40	0.70	4.69	12.60
20/01/2015	17.97	0.56	4.26	13.34
21/01/2015	17.53	0.56	4.12	13.02
22/01/2015	17.21	0.58	3.41	13.33
23/01/2015	18.23	0.48	4.28	13.38
26/01/2015	17.10	0.54	4.52	11.54
27/01/2015	18.92	0.47	7.25	13.66
28/01/2015	19.41	0.41	6.76	14.82

29/01/2015	19.53	0.46	5.78	15.39
30/01/2015	19.59	0.36	10.45	16.14
02/02/2015	17.15	0.56	3.28	12.87
03/02/2015	17.74	0.46	7.63	13.77
04/02/2015	17.75	0.50	3.70	14.11
05/02/2015	17.75	0.55	2.14	13.38
06/02/2015	17.70	0.50	4.27	13.10
09/02/2015	15.45	0.59	1.87	10.01
10/02/2015	16.83	0.55	7.11	12.10
11/02/2015	18.39	0.50	7.26	13.08
12/02/2015	19.22	0.56	9.54	14.68
13/02/2015	19.41	0.48	7.84	15.49
16/02/2015	18.49	0.62	7.04	13.48
17/02/2015	18.91	0.56	8.38	15.04
18/02/2015	20.26	0.49	9.09	14.88
19/02/2015	19.86	0.51	9.22	15.62
20/02/2015	20.68	0.45	9.01	16.32
23/02/2015	18.93	0.58	7.80	13.83
24/02/2015	20.63	0.51	9.12	15.78
25/02/2015	20.58	0.51	7.80	16.32
26/02/2015	20.85	0.45	12.16	16.61
03/03/2015	22.50	0.41	13.37	17.14
04/03/2015	23.70	0.45	15.01	19.50
05/03/2015	24.25	0.41	12.46	20.68
06/03/2015	23.02	0.40	10.67	20.28

09/03/2015	22.94	0.43	11.99	18.27
10/03/2015	23.57	0.17	12.61	20.32
11/03/2015	24.21	0.23	13.28	20.40
12/03/2015	24.64	0.23	14.06	21.35
13/03/2015	24.79	0.21	13.28	21.61
16/03/2015	22.51	0.23	9.55	18.76
17/03/2015	22.48	0.22	11.61	18.88
18/03/2015	22.15	0.26	9.74	18.60
19/03/2015	21.78	0.26	10.22	17.89
20/03/2015	21.48	0.25	11.21	17.88
23/03/2015	19.54	0.25	8.99	15.23
24/03/2015	19.22	0.25	6.96	15.89
25/03/2015	19.35	0.28	8.33	15.91
26/03/2015	17.87	0.26	5.12	15.34
27/03/2015	18.25	0.09	10.94	15.48

Table 78: Data summary of the modelling period

Model adjustment

The modelling strategy is to use multiple linear regression techniques to obtain a linear model that can evaluate the comfort level, predicting the indoor temperature that will be achieved in the building as function of the energy consumption, the outdoor temperature and the building inertia (using the previous indoor temperature, when the heating system is switched on every day).

The coefficients obtained for the three independent variables should be positive, as they make that the indoor temperature increases.

$$T_{ind}[^{o}C] = a + b \cdot E[MWh] + c \cdot T_{out}[^{o}C] + d \cdot T_{ind\_prev}[^{o}C]$$

Equation 19: Proposed comfort model for the Uc1 of SES pilot building in Zone 1

Analysis of the results and conclusions

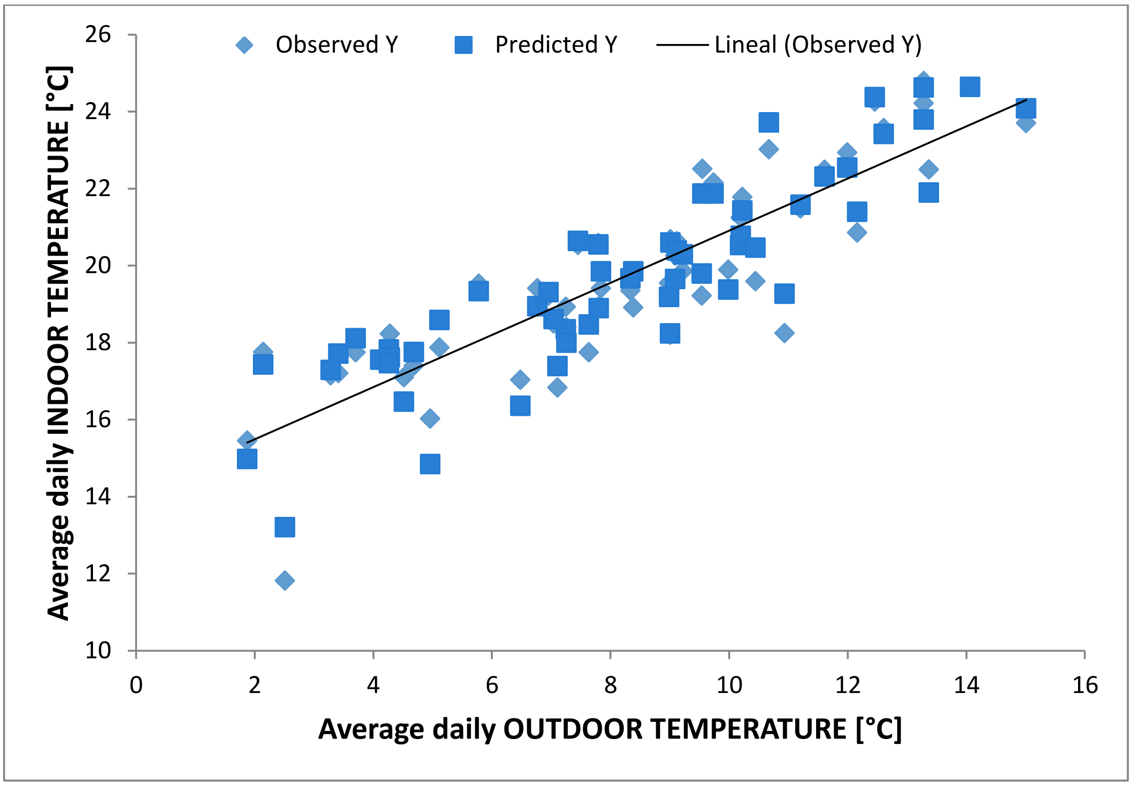

Figure 57: Adjusted regression curve with the outdoor temperature

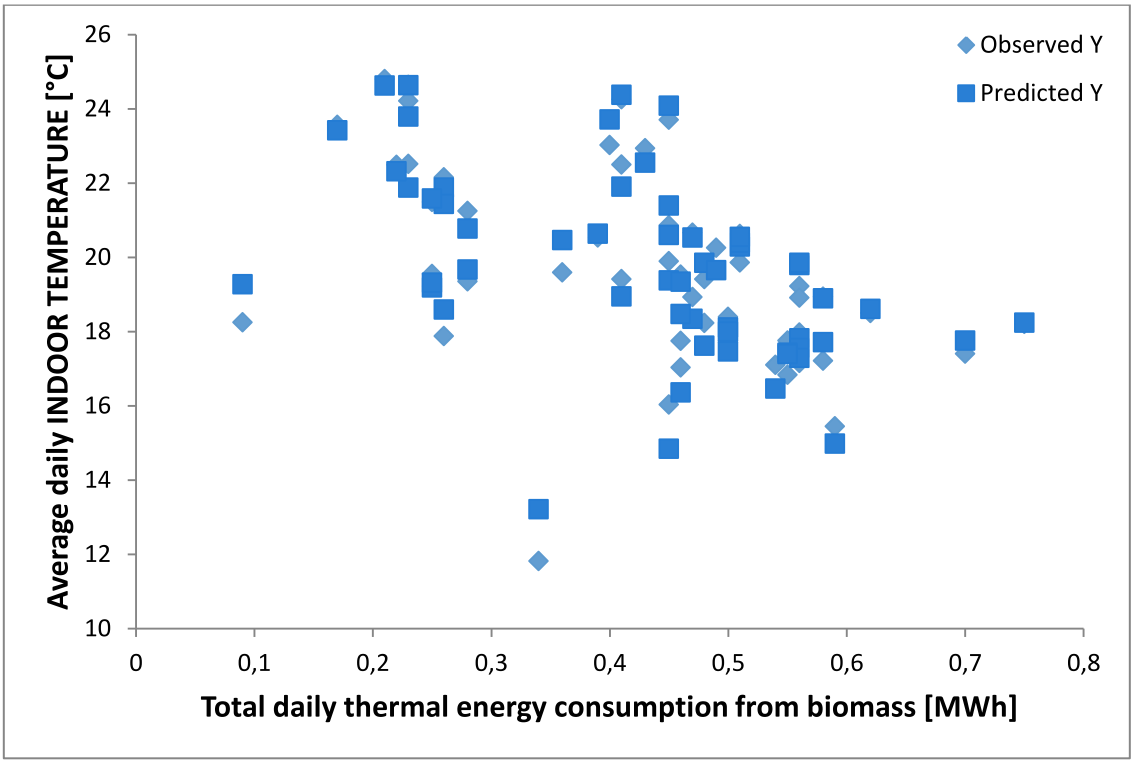

Figure 58: Adjusted regression curve with the energy consumption

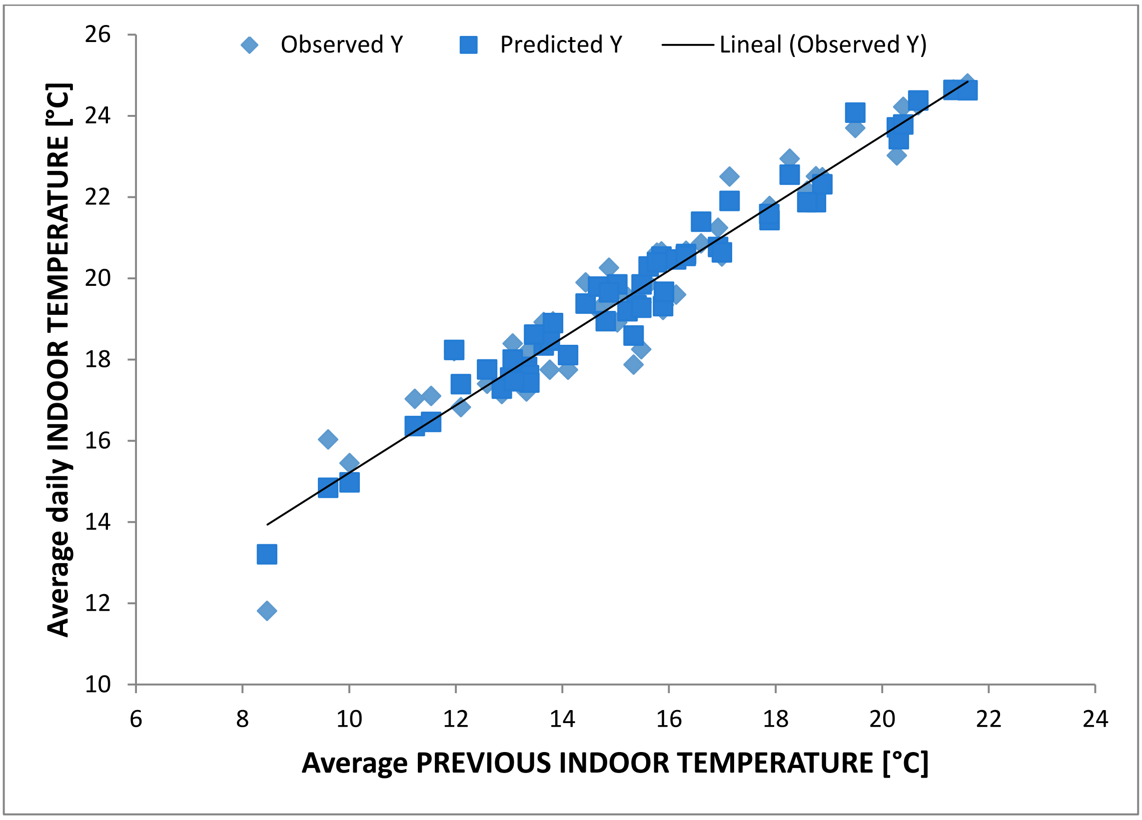

Figure 59: Adjusted regression curve with the previous indoor temperature

Regression statistics	
Coefficient of determination R^2	96%
Adjusted R^2	96%
Standard error SE	0.53
Number of observations	56

Table 79: Summary of the regression statistics

	Coefficient	SE	t-statistic	p-value
a (Intercept)	5.42	0.71	7.66	0.000
b (Slope for the energy consumption)	2.94	0.64	4.60	0.000
c (Slope for the outdoor temperature)	0.19	0.04	4.82	0.000

d (Slope for the previous indoor temperature)	0.75	0.05	16.18	0.000

Table 80: Summary of the variance analysis

The main conclusions that can be drawn for this regression analysis are the listed below:

- All the independent variables considered in the model to explain the indoor temperature are significant, being the previous indoor temperature (building inertia) and the outdoor temperature (weather conditions) the two with a higher influence in the regression. This can be due to the fact that the heating system does not meet the energy needs of the SES building, and thus, it cannot overcome the external and internal thermal conditions.
- The coefficients obtained for the three variables are consistent (positive).
- Regarding the statistic parameters, the R^2 is very high (96%) which means that the model explains almost all the variability of the data points studied. The t-statistics are good in all cases and the p-values are zero, which means that all the variables included in the model are significant.

On the basis of the conclusions above, this model for the thermal comfort level is very consistent and accurate and therefore it can be accepted. During the reporting period it will be used to evaluate the comfort improvements achieved with the implementation of the BaaS solution.

Decision making	
Decision	**TO ACCEPT THIS MODEL AND USE IT TO ASSESS THE INDOOR COMFORT IMPROVEMENTS IN SES BUILDING**

Table 81: Summary of the modelling decision making

The next equation represents the model to evaluate the comfort improvements obtained with the SES Uc1 in the zone 2 of the building.

$$T_{ind}[^{\circ}C] = 5.42 + 2.94 \cdot E[MWh] + 0.19 \cdot T_{out}[^{\circ}C] + 0.75 T_{ind\_prev}[^{\circ}C]$$

Equation 20: SES Building indoor comfort model for Zone 2

6 Final models summary

6.1 CARTIF pilot building

6.1.1 CARTIF_Uc1 (winter)

$$G = 10.82 - 0.54 \cdot T_{out} - 0.42 \cdot Rad_{previous} \text{(R}^2\text{=91\%)}$$

Equation 21: CARTIF Building: Adjusted Baseline Energy for Uc1 (normal days)

$$G = 14.35 - 0.54 \cdot T_{out} - 0.42 \cdot Rad_{previous} \text{ (R}^2\text{=91\%)}$$

Equation 22: CARTIF Building: Adjusted Baseline Energy for Uc1 (Mondays)

6.1.2 CARTIF_Uc2 (summer)

$$P[W] = 355{,}458 + 1{,}057{,}195 \cdot T_{out}[^oC] + \text{-}26{,}729{,}488 \cdot T_{indoor}[^oC] + \text{-}81{,}230 \cdot Rad[W/m^2] + 2{,}119 \cdot \cdot Day + \text{-}19{,}396 \cdot T_{out} x T_{in} + 306 \cdot T_{out} x Rad + 3{,}294 \cdot T_{out}{}^2 + \text{-}19{,}374 \cdot T_{in}{}^2 + 492{,}642 \cdot Rad^2$$

$$\text{(R}^2\text{=79\%)}$$

Equation 23: Adjusted Baseline Energy for the Uc2 of CARTIF pilot building

6.2 ZUB pilot building

6.2.1 ZUB_Uc1 (winter)

$$H[kWh] = 370.08 - 23.82 \cdot T_{out}[^oC] - 25.32 \cdot Rad[kWh/m^2] \text{ (R}^2\text{=93\%)}$$

Equation 24: ZUB_Uc1 Adjusted Baseline Energy

6.3 SES pilot building

6.3.1 SES_Uc1 (winter)

$$E = -0.10 - 0.01 \cdot T_{out} + 0.01 \cdot T_{ret} - 0.02 \cdot T_{in-1} + 0.01 \cdot T_{in} + 0.12 \cdot Day_{Monday} - 0.13 \cdot Month_{March}$$

$$\text{(R}^2\text{=76\%)}$$

Equation 25: SES_Uc1 Adjusted Baseline Energy for Uc1 for Zone 1

6.3.2 Comfort models for SES_Uc1 (winter)

$$T_{ind}[^{o}C] = 6.41 + 2.19 \cdot E[MWh] + 0.19 \cdot T_{out}[^{o}C] + 0.67 \cdot T_{ind\_prev}[^{o}C] \; (R^2=96\%)$$

Equation 26: SES Building indoor comfort model for Zone 1

$$T_{ind}[^{o}C] = 5.42 + 2.94 \cdot E[MWh] + 0.19 \cdot T_{out}[^{o}C] + 0.75 \cdot T_{ind\_prev}[^{o}C] \; (R^2=96\%)$$

Equation 27: SES Building indoor comfort model for Zone 2

7 Conclusions

After the previous deliverable D6.3.1 that described the IPMVP methodology, this document includes the analysis procedure, obtained results and conclusions that

This document focused in the definition of the baseline, which is the reference to apply the IPMVP in order to assess the energy savings achieved with the implementation and deployment of BaaS solution.

The baseline includes the definition of a baseline period, the description and selection of the variables that will be studied to explain the energy consumption (independent variables), the explanation about the parameters that are considered as static factors in the analysis, the characteristics of the model (modelling period and frequency, mathematical function, number of observations or data points) and its accuracy (R^2, SE, t-statistic...). Once a model has been developed and the results are satisfactory, the energy savings can be evaluated comparing the energy consumption between the baseline and the reporting periods.

A previous work of data collecting and processing was necessary in order to prepare and select the data for the following analyses.

Numerous studies have been conducted based on the historical data collected in the three pilot buildings (i.e. CARTIF, ZUB and SES), before obtaining valid mathematical models that accurately represent the variations on the energy consumption with variables like the outdoor temperature, solar radiation, indoor temperature, etc.

The final results obtained for the three pilot buildings are very satisfactory from a statistics point of view (high accuracy and meeting the IPMVP requirements and recommendations) and reasonable from an energy point of view. Moreover, at least in one model of each pilot building (CAR_Uc1, ZUB_Uc1 and SES_comfort) the R^2 is higher than 90%.

Finally, it is important to highlight that the final models here obtained are fundamental to accomplish the energy assessment between the baseline and the reporting period in a correct way (before and after BaaS implementation). The more accurate are the models, the better is the justification to support the energy savings. The final models that have been obtained and presented in this report will be used for the energy savings evaluation in the three pilot buildings of BaaS project and the results will be shown in the next document of this task *"D6.3.3 Reporting period"*.

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