

# **BUILDING MODELING AND SIMULATION FOR OPERATION TIME ENERGY EFFICIENCY**

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## **ABSTRACT**

The context for this paper is the meeting point of three different phenomenon that are arising at the very early 21<sup>st</sup> century society. The spread of IT technologies and worldwide economic and energy scenarios require to take advantage of the synergies of may appear among multiple application domains.

Since the Energy Performance of Buildings Directive was released in 2002 (Directive 2002/91/EC, EPBD) the energy efficiency in building domain has been a pretty big challenge for all EU Member States and specially for the stakeholders involved in the construction industry. This challenge has been faced, in most of the cases, in a monolithic approach.

In the most common scenario, building designers are not aware about the building control strategies that will be applied during the operation time and how the building envelope will perform with them. In parallel, the control engineers do not know about the building thermal inertia and its impact into the control routines. Our work tackles this parading that has been a key factor for unnecessary energy consumptions and users discomfort.

**Keywords:** energy efficiency, building modeling, optimization

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## NOMENCLATURE

AEC: Architecture, Engineering and Construction  
BacNET: Building Automation and Control Network  
BMS: Building Management System  
R-Value: Equivalent resistance  
gbXML: Green Building XML  
g- Value: Solar Factor  
HVAC: Heating Ventilation and Air Conditioning  
IFC: Industrial Foundation Class  
IT: Information Technologies  
OBIX: Open Building Information eXchange  
OPC: Object Linking and Embedding for Process Control  
OSGI: Open Source Gateway Initiative  
U- Value: Heat transmittance  
XML: eXtensible Markup Language  
W3C: World Wide Web Consortium

## INTRODUCTION

In 2010 Tecnalia<sup>4</sup> decided to create a team focused on energy efficiency and urban sustainability composed by building planners, energy management and information technologies experts. *SiMoNa* is the compilation of the experience acquired and the knowledge shared among the members of that multidisciplinary team[1].

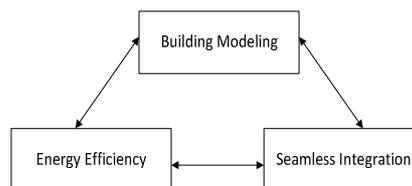
*SiMoNa* is a “smart system for monitoring and actuation” that takes as reference the building model and the forecasted weather to create 24h plans for HVAC systems, electrical loads as well as for indoor comfort set points.

The energy demands dynamic forecasting can be faced in many different ways, from simplified models based in continuous monitoring to complex building models based on statistical data[2][3][4].

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<sup>4</sup> Tecnalia, located in the Basque Country, is the largest research centre in Spain with more than 1300 employees, organized in 7 research units (Sustainable Construction, Energy & Environment, Innovation Strategies, ICT, Industry & Transport, Health, Technology Services). The team that worked in this study belongs to Sustainable Construction Unit more precisely to the Smart Building and Cities area.

*SiMoNa*'s approach considers a simplified building model feed by real weather and occupancy data. This paper describes *SiMoNa*, the integration of a building domain simulation engine into a building management system to optimize the overall building operation.



**Figure 1: *SiMoNa*'s development pillars**

## BUILDING MODELING

Integration of design tools in operation domains has been a discussion topic for years. The computing power required running the simulations and the information required to develop proper building models have been issues to solve. The development of powerful IT components and the awareness about the need of efficient workflows for business profitability lead to create the appropriate scenario to integrate design phase knowledge with operation time skills.

This work considers the building modeling from the perspective of the building physics, equipment (HVAC and lighting) and user behavior modeling. [5][6][7]

We suggest three different modeling levels that depend on the existing building design information and available control options. All of the models consider the thermal demand forecast as keystone for the optimization.

*Basic Modeling:* From the modeling point of view, mainly the building geometry, envelope's isolation level and building usage are considered. In this case the optimization will not cover the production systems optimization.

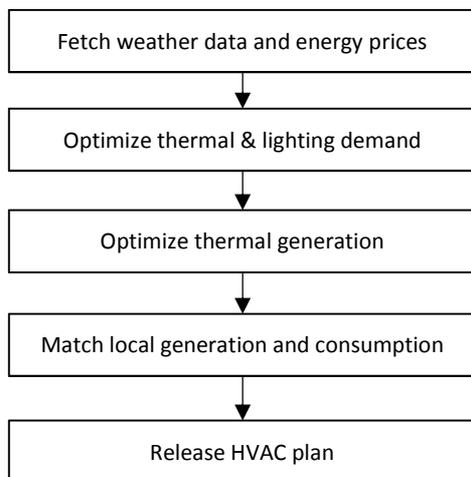
*Advanced Modeling:* In addition to the concepts included in the basic modeling approach, HVAC modeling is included. The hot and cool water (or

air) generation and distribution equipment as well as the lighting circuits are modeled. The optimization outcomes include the HVAC equipment's set points and operation periods.

*Complete Modeling:* The advanced modeling approach is a detailed enhancement of the *advanced* approach. In the *advanced* approach simplifications in the HVAC system modeling are done, mainly in terms of number or cooling and heating circuits, the *complete* approach considers the system whole complexity.

We adopted *EnergyPlus*[8] as simulation engine for forecasting and optimization processes. The optimization target is minimizing the cooling or heating energy consumption to satisfy the users' comfort requirements.

The optimization loop follows the flow described below.



**Figure 2: Optimization loop**

The optimization processes are indeed divided in sequences of steps:

- *Thermal and lighting demand optimization* relies on a sequence of preconfigured building configurations in order to identify which one is the less energy demanding one.

- *Thermal generation optimization* takes as constraint the targeted comfort level and calculates the operation points (generation and distribution temperatures) for the HVAC system to satisfy the mentioned boundary condition

The *advanced modeling level* has been selected to evaluate the development described in this document. Applied to one of the buildings of University of Mondragon its outcomes are explained in detail in the latter in this document.

The main parameters for the building physics modeling process are:

Description	Symbol	Units
Walls Equivalent resistance	R-Value	m <sup>2</sup> K/W
Solar Factor	g- Value	%
Thermal mass	M	kJ
Transmittance	U- Value	W/m <sup>2</sup> K
Ground Temperature	Ground T	K
Thermal Bridges	--	W/mK
Air tightness	--	m <sup>3</sup> /h
Glass area	--	%
Shadow factor	--	%
Floors	--	Integer
Area	--	m <sup>2</sup>

**Table 1: Main building physics parameters**

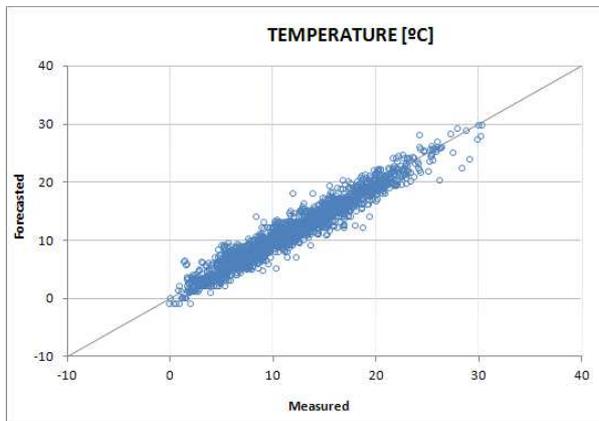
The most relevant data for building thermal performance forecast, thus, the weather forecast and building occupancy are dynamically updated and feed to the simulation engine.

The weather forecast is a key input for the simulations; two different weather information sources have been validated. The purpose of the validation is to settle if free weather forecast sources provide accurate enough information.

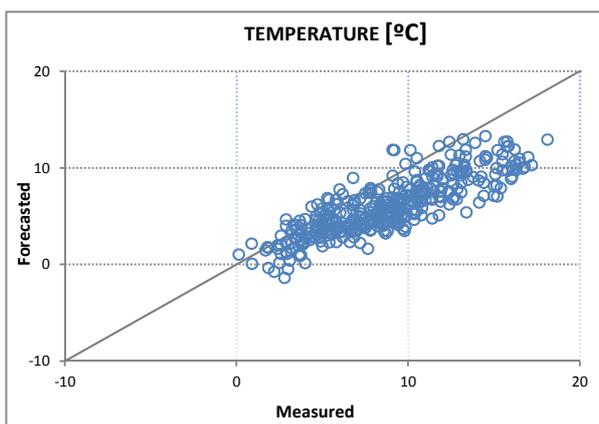
The validated weather forecast data sources are:

- *MeteoMedia* – fee based weather data source
- *NOAA* – Non fee weather data source

The next sequence of figures (3, 4) show the data obtained for outdoor temperature validation.



**Figure 3: Meteomedia data source**



**Figure 4: NOAA data source**

The values used as inputs for the thermal demand forecasting simulations are:

- Outdoor temperature.
- Wind speed
- Solar radiation
- Cloud coverage

The conclusion of the validation is that available free weather forecast sources are accurate enough

## BUILDING MODELS INTEGRATION

The application of design phase building knowledge into operation time lead to more efficient business process, thus, system engineering, and better understanding of buildings' behavior as thermal buffer.

In the context of integration our work relies in open platforms and in communication protocols supported by the W3C.

Building models supported by *gbXML* (Green Building XML) and *OBIX* (Open Building Information eXchange) provide flexibility and scalability to the overall *SiMoNa* platform. Both *gbXML* and *OBIX* are XML based information models.

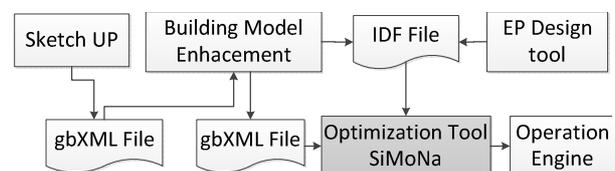
*gbXML* provides a seamless data integration platform between CAD models (i.e., REVIT) and simulation software (i.e., Radiance) in this study is used to support design of high performance buildings.

The most relevant data capabilities supported by *gbXML* are:

- 3D and 2D polygon geometry
- Opaque construction and material
- Glazing and shades
- HVAC and Lighting Controls
- Schedules

*gbXML* together with *IFC* (Industrial Foundation Class) are the two prevalent information infrastructures in the AEC (Architecture, Engineering and Construction) industry[9].

Next figure (5) shows the information model flow to feed the optimization engine.



**Figure 5 : Building information model flow**

*OBIX* has a complementary role to *gbXML*. While *gbXML* is used to model building design phase information, *OBIX* is used to exchange operation time information between *SiMoNa*'s core and the communication layer or gateway.

## ENERGY MANAGEMENT

Third pillar and final target of this study is to achieve an efficient energy management. The implemented energy management policy relies on 24h ahead accurate energy demand and local generation power forecasting in order to minimize the energy demand (thermal and lighting) and maximize self-consumption.

The relationship between lighting and heating/cooling has had a special consideration.

The adopted approach considers the conjunction of thermal gains due to the window area and the heat transfer due to the opaque surfaces.

$$Q_{sr} = S \cdot R \cdot F \quad (1)$$

$Q_{sr}$ : Solar thermal radiation through the window in *Watts*.

$S$ : Window Surface given in  $m^2$ .

$R$ : Solar radiation in Windows plane, given in  $W/m^2$

$F$ : Correction factor related to the window type.

$$Q_{str} = K \cdot S \cdot (T_{ec} - T_i) \quad (2)$$

$Q_{str}$  Solar thermal radiation through the wall in *Watts*

$K$  Thermal transmittance.

$S$  Façade surface

$T_{out}$  Outdoor temperature

$T_{in}$  Indoor temperature

For thermal optimization following parameters have been taken into consideration [10]:

- Outdoor weather conditions
- Thermal gains due indoor loads
- Thermal gains due to solar radiation
- Comfort standards

Second level optimization includes artificial lighting and electrical loads scheduling. Maximize the self-consumption is one of the mayor targets of the designed optimization process.

The total electrical consumption is the addition of the non-controlled loads (including lighting), the shiftable loads and the HVAC consumption.

Then, equation could be rewritten as follows:

$$q1_i + q2_i = q_i^{nc} + q_i^{sh} + q_i^{hvac} \quad (3)$$

i=1,..n

Where

$q1_i$ : Consumption at time-step i coming from local generation. [kW]

$q2_i$ : Consumption at time-step i purchased from market. [kW]

$q_i^{nc}$ : Consumption of non-controlled loads (including lighting) at time-step i. [kW]

$q_i^{sh}$ : Consumption of shiftable loads at time-step i. [kW]

$q_i^{hvac}$ : Consumption of HVAC system at time-step i. [kW]

$N$ : Total number of time-step of the scheduled period [-]

A shiftable is defined as a load that can be started at any of the possible periods within a defined range. This characteristic of the shiftable loads forces to introduce binary variables and convert the optimization into a binary linear programming problem[11]. The binary variables introduced in the problem description are expressed as:

$$q_i^{sh} = \sum_{k=1}^K \sum_{j=1}^{Jk} q_i^{sh, kj} \cdot s_{kj} \quad (4)$$

i=1,..,n

Where

$q_i^{sh}$ : Consumption of shiftable loads at time-step i. [kW]

$K$ : Total number of shiftable loads.

$Jk$ : Number of strategies of “k” shiftable load.

$q_i^{sh,kj}$ : Consumption of “k” shiftable load at time-step i following “j” strategy. [kW]

$s_{kj}$ : Binary variable representing “j” strategy of “k” shiftable load.

$N$ : Total number of time-step of the scheduled period.

In order to ensure that only one strategy per load will be active, the following constrain must be added.

$$\sum_{j=1}^{Jk} s_{kj} = 1 \quad (6)$$

$$k = 1 \dots K$$

Where

$Jk$ : Number of strategies of “k” shiftable load.

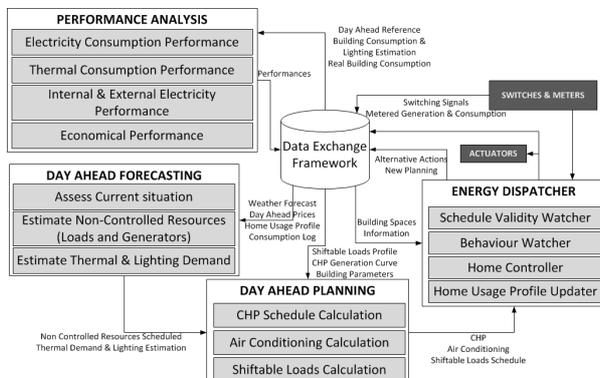
$s_{kj}$ : Binary variable representing ”j” strategy of “k” shiftable load.

$K$ : Total number of shiftable loads.

Around the optimization processes there are auxiliary processes that have a relevant role in the overall framework [12].

- *Day Ahead Forecasting* calculates thermal, electrical demands and local generation.
- *Day Ahead Planning* schedules shiftable loads and usage of local generation power.
- *Energy Dispatcher* executes the calculated schedules.
- *Performance Analysis* evaluates if new forecasting or replanning is required.

The main modules and the information exchanged among them are shown in the figure (6).



**Figure 6: Optimization and auxiliary modules**

## USE CASE: Mondragon Unibertsitatea

Located in the north of Spain Mondragon Unibertsitatea is a brand new building equipped with laboratories, workshop rooms, study areas, classes and services for 200 students [13].

In terms of HVAC equipment it includes a boiler, a chiller, supported with a heat exchanger, and three primary air handling units.

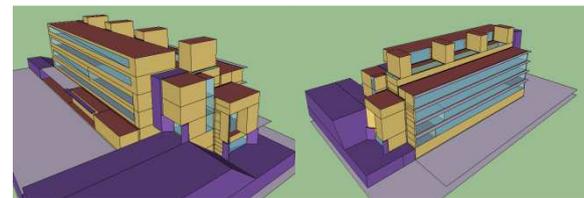
From the point of view of management policies the main constraints are:

- For all building areas, temperature set-points are fixed for winter and summer periods.
- Windows are not operable and there are fixed external shadowing devices in some of the facades.

In this context the optimization target is “to optimize the heating and cooling equipment’s consumption in order to satisfy established comfort standards” [14].

Guaranty regulation constraints for indoor spaces and end users comfort standards have had a special follow up. The team has kept close contact with building’s maintenance staff in order to early detect unconformities in any of both domains.

The 3D view of the implemented building model is shown in the figure (7).



**Figure 7: Modeled building 3D view**

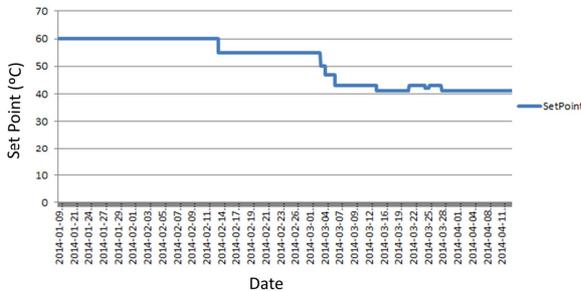
The platform deployed in Mondragon Unibertsitatea, hereinafter MU, has been integrated with an existing BMS. *SiMoNa* doesn’t replace any of the BMS functionalities but optimizes BMS’s set points. The data exchange

between the BMS and *SiMoNa* platform is done using two communication standards

- *BacNET*, to handle HVAC systems
- *OPC*, to handle lighting control network.

Completed 6 months since its deployment (January 2014) the first significant results have been released.

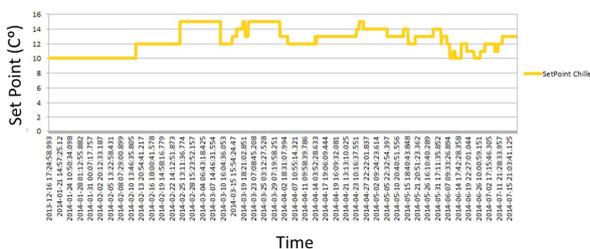
The next sequence of figures (8, 9) describes the chiller's and boiler's set-point evolution.



**Figure 8 : Boiler's set-point temperature**

The optimization process has decreased considerably boiler's operation temperature. The heating thermal demand decreases hugely since mid-March which allows decreasing the circulated hot water temperature from the used 60°C without risk for the users' comfort. In the month of April the heating demand was almost neglectable and the boiler was disabled.

For the cooling power the opposite behavior is shown.

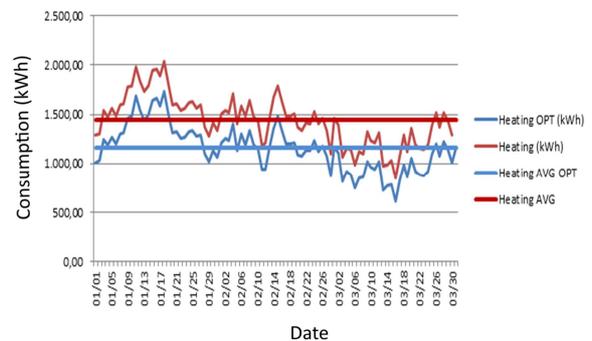


**Figure 9: Chiller set point temperature**

The standard set point for the chiller was between 7°C and 9°C. The chiller optimization was enabled in the month of February, the set point was moved

to 13°C-15°C for the months of March/April, in May/June where more cooling power was required, the set-point went again down to 10°C. It is important to notice that in the end of June and early July the set point raises again due to the low level usage of the building (less students, only office and staff activity) and consequently less cooling power required.

The impact on energy savings due to the optimization processes are summarized below.

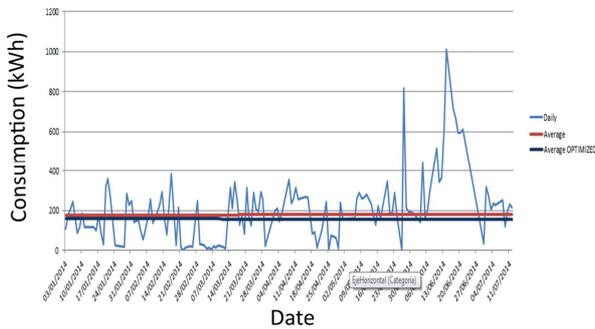


**Figure 10: Heating consumption**

In figure (10) reddish lines describe the heating, average and daily real, consumption in kWh without any optimization. Blue lines represent the heating consumption, and average, with the *SiMoNa* platform.

For the cooling domain, the chart below shows the values obtained for the cooling consumption. The *SiMoNa* platform's performance for cooling is evaluated against historical data and billing information.

The chart below shows the daily cooling consumption and the average values with the optimization platform (*SiMoNa*) running and without optimization platform.



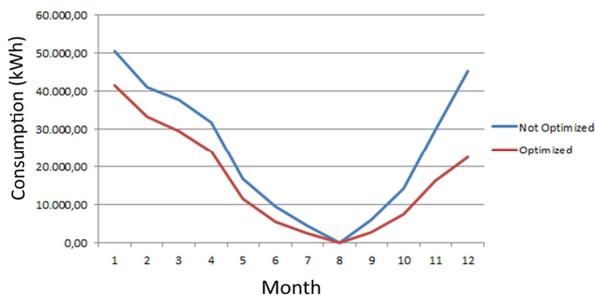
**Figure 11: Cooling consumption.**

The values for cooling and heating grouped by months are shown in the tables below. The “*standard heating/cooling consumption*” columns values are based on historical values while the “*optimized heating/cooling consumption*” values are released by the installed optimization platform.

Month	Standard Heating Consumption (kWh)	Optimized Heating Consumption (kWh)
Jan.	50.576,13	41.573,66
Febr.	41.145,05	33.206,30
March	37.884,19	29.453,17
April	31.903,78	24.166,39
May	16.744,52	11.502,68
June	9.425,03	5.505,51
July	4.760,54	3.640,54

**Table 2: Optimized vs Not Optimize heating consumption**

Based on the historical data and the real data the extrapolation for heating consumption values for complete year is shown in the figure (12).

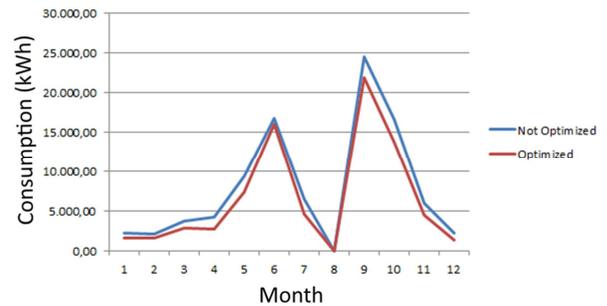


**Figure 12: Heating consumption extrapolation consumption is given in kWh.**

Month	Standard Cooling Consumption (kWh)	Optimized Cooling Consumption (kWh)
Jan.	2.230,12	2.100,86
Febr.	2.147,55	1.587,69
March	3.773,44	2.845,80
April	4.239,45	2.789,70
May	9.359,73	7.344,39
June	16.776,12	12.966,44
July	6547,89	4640,22

**Table 3: Optimized vs Not Optimize cooling consumption**

Based on the historical data and the real data the extrapolation for cooling consumption values for complete year is shown in the figure (13).



**Figure 13: Cooling consumption extrapolation consumption is given in kWh.**

*Note: The data extrapolation considers that during the summer holidays the building is closed for one month.*

## CONCLUSIONS

In order to have an accurate evaluation of the deployment we analyzed the work from three different points of view.

From the *technological challenge* point of view, thus, the overall modules integration, the main barriers arise at the *EnergyPlus* integration[15]. *EnergyPlus* is designed to use plain text files as interfaces that makes the information very accessible but on the other hand requires a deep knowledge of the input/output files format.

From the *optimization performance* point of view, the most relevant difficulty is to get an accurate building modeling. It is at this point where a good transfer of the knowledge generated at design phase can help to get proper building models and consequently efficient thermal and lighting demands forecasts[1].

Last but not least the interviewed *end users'* (building owners and maintenance personnel) perception of the platform has to be mentioned. In this context the seamless integration with the existing BMS platforms and the no need of additional refurbishment operations helps to the adoption of the platform.

The end users suggested new features as moving the optimization module to the cloud or upgrading the system to make possible to run optimization on several buildings in parallel.

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