Inspection of HVAC Systems through continuous monitoring and benchmarking
Intelligent Energy Europe Project Number: IEE-10-272
Acronym: iSERV

Complete final version of code required to integrate chosen tools into database

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Contents

1 INTRODUCTION

In the frame of iSERV project, a complex modelling has been developed in order to assume an estimate of potential savings about electric energy of buildings. This model might be able to override issues linked to lack of either metering data, or geometrical, physical information (e.g. thermal transmission of envelope). This report presents a detailed description of the modelling created so as to estimate energy savings on whole building electricity consumption due to the implementation of different ECOs ***(Energy Conservation Opportunities)***.

On the first hand, Chapter 2 provides a detailed explanation of assumptions made over the core model: e.g. data requirements, conversion from database to model. On the second hand, Chapter 3 explains both applied methodology and definition of scenarios to evaluate a range of electric energy savings. Additionally, the 13 ECOs selected for modelling are introduced.

In the iSERV tool, each ECO is analysed individually. For each ECO evaluation, the analysis starts with the calculation of monthly electrical consumption for a “case 0” (building as it is and using data stored in HERO database). Then calculation is reviewed by taking into account specific condition of the evaluated ECO. In order to be as close as possible to reality, results are expressed in terms of percentage of potential savings, i.e. percentage of savings of the second calculation relatively to the reference case. Furthermore, savings are provided for a range of values corresponding to minimum, average and maximum case scenarios (e.g. 3 cases per ECO). This allows at the same time to reduce the error in the predictions and to take into account the rough assumptions made for allowing to run the code.

Please notice that this evaluation does not take into account the analysis of any metered data. Only some basic characteristics of the buildings and their corresponding HVAC systems are taken (from HERO database) and converted to model parameters. Therefore, results provided by this analysis correspond to a theoretical estimation.

Finally, chapter 4**Error! Reference source not found.** introduces the methodology, based on ISO standard 3790, applied to estimate building energy needs regarding to heating, cooling and ventilation. Indeed these energy needs are preliminary conditions for calculation of electricity consumption of the model.

2 CORE MATLAB CODE

This chapter provides a detailed explanation about all the steps performed by the core Matlab code. They are mainly: connection to HERO database, pre-processing of data, model parameters assumptions, thermal model approach and the calculation of the electrical consumption corresponding to the HVAC system(s) and the whole building.

Figure 1 shows a general scheme of the evaluation process.

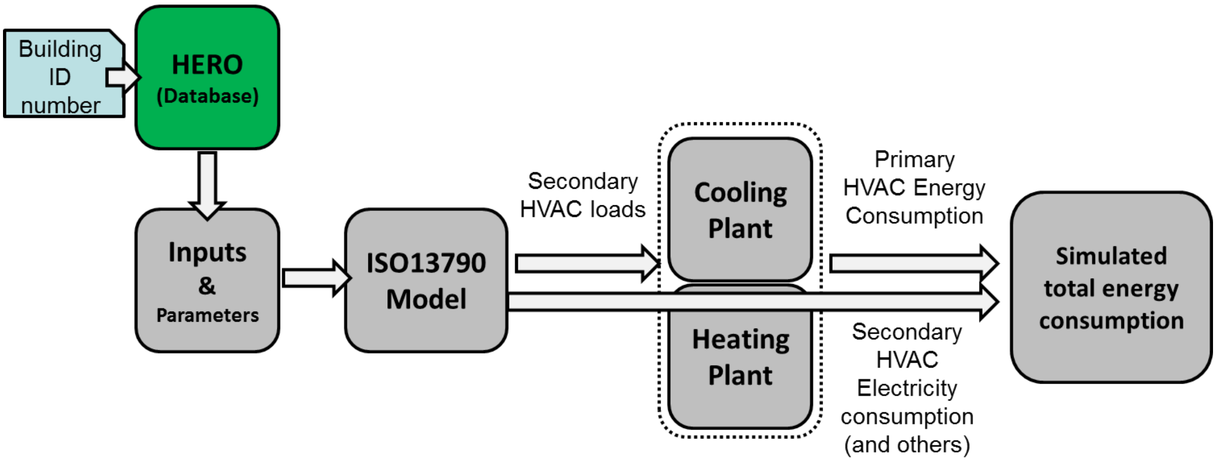

Figure 1: General scheme of the Matlab code

2.1 Data Pre-Processing

2.1.1 Getting inputs from data base

The first part of the code corresponds to the translation from the database format to Matlab language.

Each time an ECO is evaluated over a specific building, all the data stored in HERO (previously provided by the iSERV end-users in the format of EXCEL-spreadsheet) is sent to the *Matlab Workspace* shaped like *structure arrays.* ". Codes allowing to get the data from HERO database were provided by iSERV partner K2n. Thus, the Matlab code is converting each group of data from the iSERV spreadsheet into an individual array. These groups are the following:

- ➔ Building
- ➔ HVAC System
- ➔ HVAC Component
- ➔ Schedules for indoor set points and occupation
- ➔ Space

Figure 2 clarifies this point.

HVAC System

Add a HVAC System

Name*	Description	Main HVAC System*	HVAC Type*	System Classification*	System Sub-classification*	Sensor Name(s)	Meter Name(s)	Control Of Flow Temperature
HEAT FLOOR	Floor Heating	N	Heating and Natural Ventilation	Centralised System	Ground Source Heat Pump (GSHP)	None	Multiple Items	BEMS
TABS	Heating and cooling TABS	N	Full Air Conditioning (no RH control)	Centralised System	Ground Source Heat Pump (GSHP)	None	Multiple Items	BEMS
MAIN AHU	Main Air Handling Unit	Y	Heating, Cooling and Natural Ventilation	Centralised System	All Air Single Duct VAV	None	Multiple Items	BEMS

```
HVAC_System_Id    HVAC_System_Name    HVAC_System_Description       Main_HVAC_System
______________    ________________    _________________________     ________________

3640              'HEAT FLOOR'        'Floor Heating'               [0]
3641              'TABS'              'Heating and cooling TABS'    [0]
3642              'MAIN AHU'          'Main Air Handling Unit'      [1]

              System_Type_Name                     System_Classification_Name    System_Sub_Classification_Name
___________________________________________        __________________________    ________________________________

'Heating and Natural Ventilation'                  'Centralised System'          'Ground Source Heat Pump (GSHP)'
'Full Air Conditioning (no RH control)'            'Centralised System'          'Ground Source Heat Pump (GSHP)'
'Heating, Cooling and Natural Ventilation'         'Centralised System'          'All Air Single Duct VAV'

Control_Of_Flow_Temperature_Type_Name
_____________________________________

'null'
'null'
'null'
```

Figure 2: Converting spreadsheet data stored in HERO (top) into Matlab structure arrays (bottom)

2.1.2 *ECO feasibility verification - first check*

The first check equals to verifying whether the basic needed data of a building and its system(s) are available from HERO database. Consequently, if the *structure arrays* corresponding to Building, HVAC System, or HVAC Component or Space include no data: then the ECO evaluation stops, all the outputs are set to zero and an error message is provided to the user: "`'[ERROR] No data is contained for this building - ECO can not be evaluated'`".

2.2 Assumptions for model parameters

In the absence of data within the HERO database about envelope properties, geometric details, ventilation flows, etc., some values need to be estimated in order to launch any calculation of the base code for reference case. Indeed especially the thermal model based on ISO 13790 needs to be fed with a specific range of inputs (e.g. meteorological conditions, activity, thermal transmission of envelope).

This part of the code creates some quantitative and/or qualitative (categorical) variables by catching some data contained in the *structure arrays*. These variables are used to make some assumptions about information not contained in HERO which is necessary to calculate thermal loads and consequently the electrical consumption of HVAC components. The way how these parameters are assumed and then used in the code can be clearly noticed by the reader in the course of this report without needing any detailed explanation.

2.2.1 *Climatic conditions*

The chosen approach considers the use of climate data such as:

- ➔ Monthly mean external air temperature [°C]

➔ Monthly mean incident solar radiation for planes at relevant orientations (N, E, S, W) and tilt angles (90°) [W/m^2].

This data is pre-computed from hourly data for different climatic zones. Given the wide range of participant countries (27) and the impossibility of getting information for each one, five climatic zones have been defined so as to cover all stakeholders. These five zones are linked to five representative city, which provides climatic data for the all the cities covered into each zone. Selection of these five climatic zones for Europe is based on the previous work done in the frame of the "Keepcool" project. The latter assumes that solar radiation and cooling degree days (15°C) are the key parameters regarding summer severity and that the heating degree days (15°C) is the key parameters for winter severity. In the Keepcool project these parameters have been first calculated for 30 cities in Europe (Figure 4 and Figure 5). The conclusion of the analysis led to 5 different representative climatic zones (Figure 3).

In regard to our own analysis, country and latitude of a specific building determines in which meteorological zone this building is located. Details are given in

Table 1.

Representative cities
Stockholm
Paris
Milan
Lisbon
Palerme

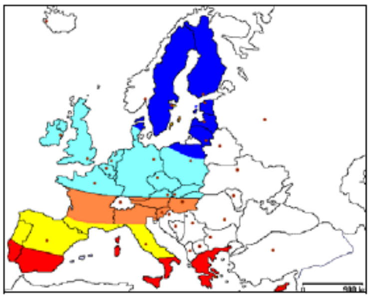

Figure 3: European climatic zones defined in the frame of Keepcool project

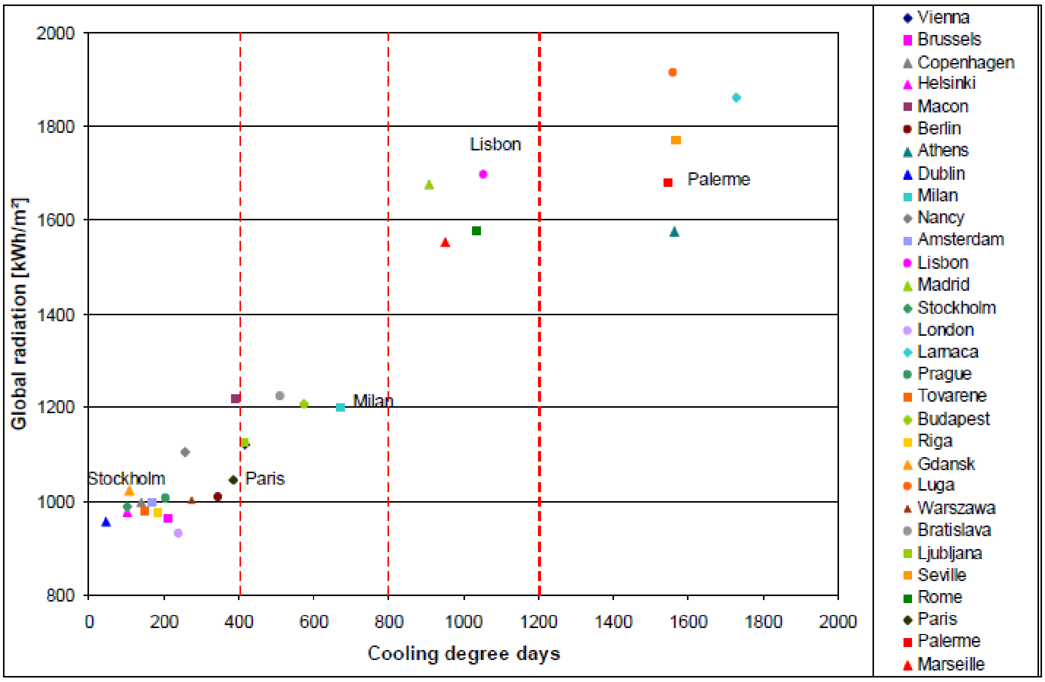

Figure 4: Cooling degree days (15°C) calculated for 30 cities in Europe

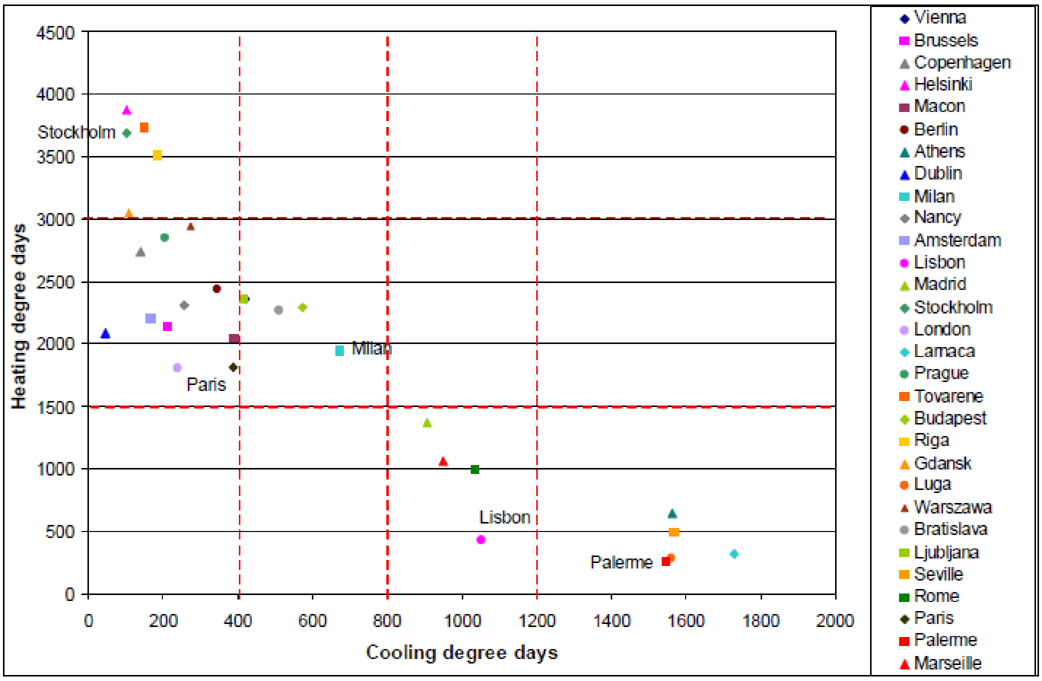

Figure 5: Heating degree days (15°C) calculated for 30 cities in Europe

Table 1 – Climatic zones by country and latitude

	1st Zone	2nd Zone	3rd Zone	4th Zone	5thZone
	Palermo	**Lisbon**	**Milan**	**Paris**	**Stockholm**
Austria			[0;48°N]	]48°N;90°N]	
Belgium				x	
Bulgaria		x			
Cyprus	x				
Czech Republic				x	
Denmark				[0;57°N]	]57°N;90°N]
Estonia					x
Finland					x
France		[0;44°N]	]44°N;47°N]	]47°N;90°N]	
Germany				x	
Greece	x				
Hungary			[0;48°N]	]48°N;90°N]	
Ireland				x	
Italy	[0;41°N]	]41°N;44°N]	]44°N;90°N]		
Latvia					x
Lithuania					x
Luxembourg				x	
Malta	x				

Netherlands				x	
Poland				[0;54°N]	]54°N;90°N]
Portugal	[0;39°N]	]39°N;90°N]			
Romania			[0;48°N]	]48°N;90°N]	
Slovakia				x	
Slovenia			x		
Spain	[0;39°N]	]39°N;90°N]			
Sweden					x
United Kingdom				x	

2.2.2 Main building characteristics (default values)

Previous sub-chapters explain that only general information about building and space characteristics is available from HERO database: e.g. year of construction, floor area, height (not mandatory field) and sector description. Lack of complementary data is the main barrier to calculate accurate monthly energy demand and consumption.

Since the information is provided in the iSERV spreadsheet in terms of "spaces", ***for this approach, each space is assumed to correspond to a single zone***. In the absence of real geometric data, ***each zone is assumed to correspond to a single building***: i.e. 4 external walls, ground floor, roof, windows within each façade.

In order to run the thermal model (ISO standard 13790), main code requires basic data such as: e.g. geometric and envelope data, orientation, occupancy, lighting and appliances gains densities, ventilation flows rate, heat recovery efficiency (if applicable).

Thus, the first assumption to estimate this data implies to shorten the list of sector types assigned to spaces (in HERO database) from 32 options to a list of 9 buildings types according to ISO 13790. Final list includes: accommodation, assembly, catering, education, health care, large space, office, shop and sports. The agreement between "sector in HERO database" and "sector in ECO" is provided in Table 2.

Table 2 – Agreement between "sector in HERO" and "sector in ECO" used by core model

Sector in HERO	Sector in ECO
Airport terminals	Large space
Bus Station/Train Station/Seaport Terminal	Large space
Car Parks 24 hrs	Large space
Community/Day Centre	Education
Crown and County Courts	Education
Dwelling	Accommodation
Emergency Services	Health care
Further Education / Universities	Education
Hospital	Health care
Hotel	Accommodation

Industrial Process Building	Large space
Laundry	Catering
Libraries/Museums/Galleries	Education
Miscellaneous 24hr activities	Health care
Nursing Residential Homes and Hostels	Accommodation
Office	Office
Primary Health Care Buildings	Health care
Primary School	Education
Prisons	Education
Residential Institutions - Residential Schools	Accommodation
Restaurant/Public House	Catering
Retail	Shop
Retail Warehouses	Large space
Secondary School	Education
Social Clubs	Office
Sports Centre/Leisure Centre	Sports
Sports Ground Arena	Sports
Stand Alone Utility Block	Accommodation
Telephone Exchanges	Shop
Theatres/Cinemas/Music Halls and Auditoria	Assembly
Warehouse and Storage	Shop
Workshops/Maintenance Depot	Sports

Reference: *ISO/FDIS 13790:2007(E) - Annex G (informative) - Table G.12: Example of conventional input data related to occupancy.*

Once a building type is assigned to each building space, a group of parameters is estimated:

1. Space height (only used if not provided by HERO) [m]
2. Occupancy metabolic rate density [W/m^2]
3. Lighting peak power density [W/m^2]
4. Appliances peak power density [W/m2]
5. Building compactness [m]
6. Airflow rate with external air per conditioned floor area [m^3/(h-m^2)]

Table 3 summarizes the estimated values.

Table 3 – Compactness, appliances, lighting and occupancy values

	Height [m]	Occupancy [W/m^2]	Lighting [W/m^2]	Appliances [W/m^2]	Building Compactness [m]	Ventilation flow rate [m^3/h-m^2]
Offices < 1500 m^2	3	4	10.8	8.1	2.1	0.7
Offices >= 1500 m^2	3	4	10.8	8.1	5.1	0.7
Education	4	7	15.1	10.1	4.4	0.7
Hospitals	3	3	13	23.7	6.5	1.0

Catering	3	16	10.8	6.9	2.1	1.2
Trade	4	8	16.2	4.3	3.7	0.7
Assembly	5	13	15.1	2.6	3.6	0.7
Accommodation	3	2	7.6	4.8	3.4	0.7
Sports	5	11	15.1	2.6	3.6	0.7
Large space	10	3	15	5	9.5	0.7

Reference: *Values are based on standardized assumptions for US non-residential buildings (Stocki et al., 2007) and ISO13790 – Annex G standard input data.*

Regarding to envelope characteristics, another following parameters are also estimated (based on construction year).

1. K level value
1. Solar heat gain coefficient of glazing [-]
2. Global envelope heat transfer coefficient [W/m^2-K]
3. Infiltration change rate per zone [1/h]
4. Heat recovery efficiency (only if applies) [-]

Table 4 summarizes the estimated values.

Table 4 – k level, g value of glazing, infiltration air change and heat recovery efficiency.

Construction year	K level [-]	g_{value} [-]	ACH [1/h]	Heat Recovery [-]
≤ 1970	150	0.85	1.5	0
≤ 1984	110	0.85	1.2	0
≤ 1996	70	0.7	1	0.3
≤ 2006	55	0.7	0.8	0.45
≤ 2010	45	0.7	0.5	0.6
> 2010	35	0.6	0.35	0.7

The approach implemented in this work simplifies the envelope heat transfer by calculating a global heat transfer coefficient (U_m). This global heat transfer coefficient is function of the K level coefficient (K) and a reference heat transfer coefficient which in turn is function of the compactness (C).

Following equation shows how to calculate U_m:

$$U_m = \frac{K}{100} * U_{m_{ref}} \qquad \textbf{(2.1)}$$

Where:

IF $C < 1$ ⇨ $U_{m_{ref}} = 1$

IF $1 \leq C \leq 4$ ⇨ $U_{m_{ref}} = \frac{C+2}{3}$

IF $C > 4$ ⇨ $U_{m_{ref}} = 2$

In order to clarify these concepts:

- ➔ K level is a measure of the overall thermal insulation level of a building.
- ➔ Compactness is a measure of shape which corresponds to the ratio between the protected volume of the building and its heat loss surface.

Reference: *http://www.energieplus-lesite.be/index.php?id=15007 (April 2014)*

2.3 Converting spreadsheet schedules to average daily operation hours

Model operation data is provided by HERO database: e.g. hourly schedule values over a week. Since the core thermal model (ISO 13790); and the whole analysis is done in a monthly time scale, then input schedules have to be converted into monthly average operation time (hours/day or hours/month). Figure 6 represents an example of schedule in the iSERV spreasheet format.

The procedure is repeated for each group of schedules (if more than 1) and for each individual one: i.e. indoor heating set point, indoor cooling set point, indoor humidity control and occupancy.

Then, each obtained set of monthly operating hours is assigned to the corresponding zones. This helps in a subsequent step to calculate energy consumption of lighting, appliances and HVAC systems.

In order to understand better this nomenclature, in this report is agreed that: *1 group of schedules = 4 individual schedules (indoor heating, indoor coiling, indoor humidity control and occupancy)*.

Schedule Name		Applies From	Applies To
Schedule 1 - Whole Building	Date Range	01/01	31/12
Time Control Method		**Upper Limit**	**Lower Limit**
Optimum Stop/Start	RH Range	40%	60%

Day			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Mon	H						21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	
		C						22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	
		RH						y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	
		Occ							10	60	200	200	200	200	200	200	200	200	200	200	60	10				
	Tue	H						21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	
		C						22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	
		RH						y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	
		Occ							10	60	200	200	200	200	200	200	200	200	200	200	60	10				
	Wed	H						21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	
		C						22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	
		RH						y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	
		Occ							10	60	200	200	200	200	200	200	200	200	200	200	60	10				
	Thu	H						21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	
		C						22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	
		RH						y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	
		Occ							10	60	200	200	200	200	200	200	200	200	200	200	60	10				
	Fri	H						21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	
		C						22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	
		RH						y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	
		Occ							10	60	200	200	200	200	200	200	200	200	200	200	60	10				
	Sat	H																								
		C																								
		RH																								
		Occ																								
	Sun	H																								
		C																								
		RH																								
		Occ																								

Figure 6: iSERV spreadsheet format for one “group of schedules”

2.3.1 ECO feasibility verification - second check

The second check equals to verifying the proper definition of the range of application of schedules in HERO. In the case that definition of periods has not been properly done: the ECO evaluation stops, all the outputs are set to zero and following error message is provided to the user: “`'[ERROR] Missing or incorrect schedule when one is required for this ECO - Please review the schedules for this building'`”.

If this check succeeds, an additional one is carried out. The latter consists in verifying whether schedules have been properly filled up and none of them are empty.

- ➔ Condition 1: Occupation is empty for all the groups of schedules -> *potential error*
- ➔ Condition 2: Heating and cooling are empty in the same group of schedules -> *error*

Due to the amount of buildings presenting incomplete schedule data and in order to increase the sample of assessed buildings, another condition related to the number of group of schedules has been established.

- ➔ If the condition 1 is filled but the number of group of schedules is equal to 1: then the monthly average occupancy hours is set as the minimum value between heating and cooling operation time. Also, following warning message is sent to the user: `'[WARNING] No occupancy schedule has been provided - Some assumptions were made'`

➔ If the condition 1 and the number of group of schedules is greater than 1: then the ECO evaluation stops, all the outputs are set to zero and the user get the following error message : '[ERROR] Missing or empty schedule values - Please complete schedules for this building'. Same situation occurs if regardless the number of group of schedules, condition 2 is met.

2.3.2 Operation time

Once checking steps success, the daily average operation time is calculated for each month of year and assigned to the corresponding zones. They correspond to:

1. Average daily occupancy hours per month and zone [h/day]
2. Average daily indoor heating temperature set point hours per month and zone [h/day]
3. Average daily indoor cooling temperature set point hours per month and zone [h/day]

Some other operation times, such as heat gains and ventilation ones are also needed.

Heat gain operation time per month and zone (t_{hgn}) are calculated for week, weekends and monthly average as show in equations (2.2), (2.3) and (2.4).

$$t_{hgn_{wd}} = t_{occ_{wd}} + 0.1 * \left(24 - t_{occ_{wd}}\right) \quad \textbf{(2.2)}$$

$$t_{hgn_{we}} = t_{occ_{we}} + 0.1 * \left(24 - t_{occ_{we}}\right) \quad \textbf{(2.3)}$$

$$t_{hgn_{avg}} = \left(5 * t_{hgn_{wd}} + 2 * t_{hgn_{we}}\right)/7 \quad \textbf{(2.4)}$$

The obtained values are used as monthly average operation time for lighting and appliances.

For ventilation operation time per month and zone (t_{ve}) is calculated for week, weekends and monthly average as show in equations (2.5), (2.6) and (2.7).

$$t_{ve_{wd}} = \max\left(t_{set_{h_{wd}}}, t_{set_{c_{wd}}}\right) \quad \textbf{(2.5)}$$

$$t_{ve_{we}} = \max\left(t_{set_{h_{we}}}, t_{set_{c_{we}}}\right) \quad \textbf{(2.6)}$$

$$t_{set_{avg}} = \max\left(t_{set_{h_{avg}}}, t_{set_{c_{avg}}}\right) \quad \textbf{(2.7)}$$

2.3.3 Indoor temperature set point values

Only indoor heating and cooling temperature set points ($T_{i_{set_{h1}}}$ and $T_{i_{set_{c1}}}$) are calculated. Night setback values are estimated as next equations.

Heating [°C] $$T_{i_{set_{h2}}} = T_{i_{set_{h1}}} - 5 \quad \text{(2.8)}$$

Cooling [°C] $$T_{i_{set_{c2}}} = T_{i_{set_{c1}}} + 10 \quad \text{(2.9)}$$

Relative humidity is not used since latent loads are not taken into account in this approach.

2.4 Recognizing services from components to zones (coupling zones ⇨ systems ⇨ components)

The main goal of this process is to associate all the existing HVAC components to the systems they compose to finally be associated to the zones they serve. This procedure will allow (in the subsequent steps) to:

- ➔ Determine the presence of some services (e.g. mechanical ventilation, indoor heating or cooling) in a desired zone in order to perform the heat balance and determine the heating and cooling loads
- ➔ As schedules are assigned to zones, extrapolate their definition to components in order to calculate electrical consumption

Following sections describe all the steps.

2.4.1 Summary of components

HERO database includes the 13 following component types:

1. Air Handling Units
2. All in One Systems
3. Cold Generators
4. Dehumidification
5. Flow Control
6. Heat Generators
7. Heat Pump
8. Heat Recovery
9. Heat Rejection
10. Humidifiers
11. Pumps
12. Storage Systems
13. Terminal Units

This step consists in recognizing and making a summary of all the HVAC components present in the facilities according to the list shown above.

2.4.2 Recognizing components per systems

This second step consists in identifying all the systems that a component serves. According to the definition of system used in iSERV project, one component may serve more than one system.

The output of this process is a matrix with a number of rows equal to the number of components and a number of columns equal to the number of systems. The matrix contains values of 1 or 0 depending on the presence or not of such component in a system.

2.4.3 Recognizing systems per zones

The third step consists in identifying all the zones that a system serves.

The output of this process is a matrix with a number of rows equal to the number of systems and a number of columns equal to the number of zones. The matrix contains values of 1 or 0 depending on the presence or not of such system in a zone.

2.4.4 Recognizing components per zones (through systems)

As components serve systems and systems serve zones, the last identification corresponds to identify which components serve which zones. The transition from components to systems to zones is done by multiplying both matrix previously created.

The output of this process is a matrix with a number of rows equal to the number of components and a number of columns equal to the number of zones. The matrix contains values of 1 or 0 depending on the presence or not of such component in a zone.

This matrix format allows for each zone an easy identification of the services available in it: only by looking for a desired component in the matrix columns.

2.4.5 Recognizing Services per zones

In order to be able to properly build the energy balance for each zone when calculating thermal loads, services that are allowed or not (boundary conditions) are assigned to each considered zone.

2.4.5.1 Occupancy allowance

If any terminal unit or handling unit serves a specific zone then occupancy is allowed in that zone.

2.4.5.2 Artificial lighting allowance

Artificial lighting is allowed for all the zones.

2.4.5.3 Appliances allowance

If occupancy is allowed in a specific zone then appliances are allowed too.

2.4.5.4 Mechanical Ventilation allowance

If any handling unit serves a specific zone then mechanical ventilation is allowed in that zone.

Conditioned ventilation presence is also checked (to calculate ventilation loads). So, if any of the air handling units (subtype) serving a specific zone is: *“Supply and extract with heating and cooling variants”* or *“Supply with heating and cooling variants”* then conditioned mechanical ventilation is allowed in that zone.

2.4.5.5 Indoor Heating allowance

If any terminal unit, all in one system, heat generator or heat pump serves a specific zone then indoor heating is allowed in that zone.

2.4.5.6 Indoor Cooling allowance

If any terminal units, all in one system, cool generator or heat pump serves a specific zone then indoor cooling is allowed in that zone.

2.4.5.7 Heat Recovery allowance

If any heat recovery component serves a specific zone then heat recovery is allowed in that zone.

2.5 Thermal Loads Calculation (ISO 13790 Model)

The output of this process is a matrix with a number of rows equal to 12 months of year and a number of columns equal to the number of zones.

2.5.1 Model parameter assumptions

The global hypotheses applied in all the cases are listed below:

- Window to wall ratio equal to 0.5
- Window surfaces are equally divided all over the external wall (4 facades)
- Window to frame ratio of 0.95
- Internal heat capacity of zones corresponding to "medium class". $C = 165000 * A_f$ [J/K]. Where, A_f is the zone surface in m^2.

2.5.2 Internal gains

The calculation of internal gains is done for each zone. For details see subchapter 4.1. Internal gains are provided in [kWh/month]. The output of this process is a matrix with a number of rows equal to 12 months of year and a number of columns equal to the number of zones.

2.5.3 Transmission and ventilation losses

The calculation of transmission and ventilation losses is done for each zone. For details see subchapter 4.1. Transmission and ventilation losses are provided in [kWh/month]. The output of this process is a matrix with a number of rows equal to 12 months of year and a number of columns equal to the number of zones.

2.5.4 Dimensionless utilization factor

The calculation of dimensionless utilization factors for gains and heating losses is done for each zone. For details see subchapter 4.1.

2.5.5 Building indoor energy needs

The calculation of continuous and intermittent heating and cooling needs is done for each zone. For details see subchapter 4.1. Continuous and intermittent heating and cooling needs are provided in [kWh/month]. The output of this process are two matrix with a number of rows equal to 12 months of year and a number of columns equal to the number of zones.

2.5.6 Mechanical ventilation needs

The calculation of heating and cooling mechanical ventilation needs is done for each zone. For details see subchapter 4.1. Heating and cooling mechanical ventilation needs are provided in [kWh/month]. The output of this process are two matrix with a number of rows equal to 12 months of year and a number of columns equal to the number of zones.

2.5.7 Length of heating and cooling seasons

The calculation of the length of heating and cooling seasons is done for each zone. For details see subchapter 4.1. Length of heating and cooling seasons is provided in [%]. The output of this process are two matrix with a number of rows equal to 12 months of year and a number of columns equal to the number of zones.

2.6 Converting calculated energy demands from zones to systems

As indoor and mechanical ventilation heating and cooling energy needs are calculated in terms of zones, they should be converted from zones to components passing through systems.

Heating needs are apportioned to the existing all in one system, heating generator and heat pumps. Cooling needs are apportioned to the existing all in one system, cooling generator or heat pumps.

An emission efficiency of 0.95 is assumed for all the energy needs.

In the case that more than one type of component serves a zone, the zone load is divided in equal parts and assigned to each one.

2.7 Monthly electrical consumption of components

2.7.1 ECO feasibility verification - third check

The third check implies to verify whether the basic data requirements about the components are available in HERO.

- ➔ ***If no data are found for nominal power of components (empty)***; the ECO evaluation stops, all the outputs are set to zero and the following error message is sent to the user: "`'[ERROR] No electrical nominal power has been provided for any component - ECO can not be evaluated'`"
- ➔ ***If incomplete data are found for nominal power of components***; the ECO evaluation continues, the missing values are set to zero and the following warning message is sent to the user: "`'[WARNING] Nominal electrical power has not been provided for some components - Values were set to zero'`"
- ➔ ***If no or incomplete data are found for coefficient of performance (COP) of all in one systems***; the ECO evaluation continues, the missing values are set to zero and the following warning message is sent to the user: "`'[WARNING] Coefficient of performance (COP) has not been provided for some All in One Systems - Assumptions were made'`"
- ➔ ***If no or incomplete data are found for coefficient of performance (COP) of heat generators***; the ECO evaluation continues, the missing values are set to zero and the following warning message is sent to the user: "`'[WARNING] Coefficient of performance (COP) has not been provided for some Heat Generators - Assumptions were made'`"

  This is only valid when heat generators are: Air Source Heat Pump (ASHP), Ground Source Heat Pump (GSHP) or Water Source Heat Pump (WSHP).

- ➔ ***If no or incomplete data are found for coefficient of performance (COP) of heat pumps***; the ECO evaluation continues, the missing values are set to zero and the following warning message is sent to the user: “'[WARNING] Coefficient of performance (COP) has not been provided for some Heat Pumps - Assumptions were made'”

- ➔ ***If no or incomplete data are found for energy efficiency ratio (EER) of all in one systems***; the ECO evaluation continues, the missing values are set to zero and the following warning message is sent to the user: “'[WARNING] Energy Efficiency Ratio (EER) has not been provided for some All in One Systems - Assumptions were made'”
- ➔ ***If no or incomplete data are found for energy efficiency ratio (EER) of cold generators***; the ECO evaluation continues, the missing values are set to zero and the following warning message is sent to the user: “'[WARNING] Energy Efficiency Ratio (EER) has not been provided for some Cold Generators - Assumptions were made'”
- ➔ ***If no or incomplete data are found for energy efficiency ratio (EER) of heat pumps***; the ECO evaluation continues, the missing values are set to zero and the following warning message is sent to the user: “'[WARNING] Energy Efficiency Ratio (EER) has not been provided for some Heat Pumps - Assumptions were made'”

Every time that a COP or EER value is missing, a new reference one will be supposed. For these cases, the assumptions are shown in the next section.

2.7.2 Monthly electrical consumption component by component

In order to calculate monthly electrical consumption of components, the following procedure is performed for each one:

1. Presence of each component is analysed, as well as index (position in a vector) of the zone(s) it serves (one or more)
2. If the component manages some energy needs (i.e. cold generators), total of needs (according to the zones it serves) and then the monthly consumptions are calculated
3. If the component works according to a specific schedule (i.e. pumps), total number of operating hours (according to the zones it serves) and then the monthly consumptions are calculated
4. Once the procedure is done for all the components, the total HVAC monthly consumptions are calculated

2.7.2.1 Air Handling Units

The existing subtypes of air handling units in HERO are:

1. Extract only
2. Fresh air only or Mixed air
3. Supply and extract
4. Supply and extract with heating and cooling variants, etc.
5. Supply only
6. Supply with heating and cooling variants

For each air handling unit, the electrical consumption is calculated according to the following equation (monthly base):

$$W_{AHU} = \Delta t \cdot \dot{W}_{AHU,n} \qquad \textbf{(2.10)}$$

Where:

Δt ⇨ Monthly mechanical ventilation operation time

$\dot{W}_{AHU,n}$ ⇨ AHU nominal power

VAV air handling units have not been taken into account.

2.7.2.2 All in One System

The existing subtypes of all in one system in HERO are:

1. ASHP Heating Only
2. ASHP Cooling Only
3. ASHP Reverse Cycle - Heating Optimised
4. ASHP Reverse Cycle - Cooling Optimised
5. GSHP Heating Only
6. GSHP Cooling Only
7. GSHP Reverse Cycle - Heating Optimised
8. GSHP Reverse Cycle - Cooling Optimised
9. WSHP Heating Only
10. WSHP Cooling Only
11. WSHP Reverse Cycle - Heating Optimised
12. WSHP Reverse Cycle - Cooling Optimised

All in one system correspond to non-centralized heat pump for heating and/or cooling. For each of them, the electrical consumption is calculated according to the following equation (monthly base):

$$W_{ALL,1} = \frac{\dot{Q}_{dem}}{COP\ or\ EER} \tag{2.11}$$

Where:

$\dot{Q}_{dem}$ ⇨ Total heating and/or cooling demand for all the zones it serves

COP ⇨ Coefficient of performance

EER ⇨ Energy efficiency ratio

As COP or EER are not mandatory fields in the iSERV spreadsheet, in the case that are missing, a value of 2.5 for heating and 3 for cooling are assumed. No distinction is made according to heat source (air, water, ground, etc.).

If more than one all in one system serving the same zone exist, then demands are divided in equal parts.

2.7.2.3 Cold Generators

The existing subtypes of cold generators in HERO are:

1. Absorption Chillers
2. Centrifugal Liquid Chillers
3. Direct evaporative cooler
4. District Cooling
5. Dry Coolers & Cooling Tower

6. Indirect evaporative cooler
7. Reciprocating Liquid Chillers
8. Screw Liquid Chillers

For each cold generator the electrical consumption is calculated according to the following equation (monthly base):

$$W_{CGEN} = \frac{\dot{Q}_{dem}}{EER} \quad \textbf{(2.12)}$$

Where:

$\dot{Q}_{dem}$ ⇨ Total cooling demand for all the zones it serves

EER ⇨ Energy efficiency ratio

As EER is not mandatory field in the iSERV spreadsheet, in the case that is missing a value of 3 is supposed.

Until now only classical chillers are calculated.

If more than one chiller serving the same zone exist, then demands are divided in equal parts.

2.7.2.4 Dehumidification

The only one subtype of dehumidification in HERO is desiccant wheel dehumidifier. For each dehumidification component, the electrical consumption is calculated according to the following equation (monthly base):

$$W_{DEHUM} = \Delta t \cdot \dot{W}_{DEHUM,n} \quad \textbf{(2.13)}$$

Where:

Δt ⇨ Monthly mechanical ventilation operation time corrected by the fraction of month of the cooling season

$\dot{W}_{DEHUM,n}$ ⇨ Nominal power

2.7.2.5 Flow Control

The existing subtypes of flow control components in HERO are:

1. Direct Variable Speed Drive
2. Magnetic/Viscous/Slip Coupling Variable Speed Drive
3. Motorised dampers
4. Motorized valves

For each flow control component, the electrical consumption is calculated according to the following equation (monthly base):

$$W_{FCTR} = \Delta t \cdot \dot{W}_{FCTR,n} \quad \textbf{(2.14)}$$

Where:

Δt ⇨ Monthly mechanical ventilation operation time

$\dot{W}_{FCTR,n}$ ⇨ Nominal power

2.7.2.6 Heat Generators

The existing subtypes of heat generators in HERO are:

1. Air Source Heat Pump (ASHP)
2. Biomass boiler
3. CHP (Combined heat and power)
4. Co-generation
5. District Heating
6. Electric Boilers
7. Fuel Fired Boilers
8. Ground Source Heat Pump (GSHP)
9. Solar collectors (to evaluate)
10. Solar Hot Water Panels
11. Water Source Heat Pump (WSHP)

Depending on the subtype, the electrical consumption may be calculated in different ways. For Air Source Heat Pump (ASHP), Ground Source Heat Pump (GSHP) or Water Source Heat Pump (WSHP) the electrical consumption is calculated according to the following equation (monthly base):

$$W_{HGEN} = \frac{\dot{Q}_{dem}}{COP} \tag{2.15}$$

Where:

$\dot{Q}_{dem}$ ⇨ Total heating demand for all the zones it serves

COP ⇨ Coefficient of performance

As COP is not mandatory field in the iSERV spreadsheet, in the case that is missing a value of 2.5 is assumed.

For "Electric boilers" the electrical consumption (monthly base) is assumed to be the same as heating energy demand ($\dot{Q}_{dem}$).

For the remaining heat generators, the electrical consumption is calculated according the following equation (monthly base):

$$W_{HGEN} = \Delta t \cdot \dot{W}_{HGEN,n} \tag{2.16}$$

Where:

Δt ⇨ Monthly indoor heating operation time corrected by the fraction of month of the heating season

$\dot{W}_{HGEN,n}$ ⇨ Nominal power

2.7.2.7 Heat Pump

The existing subtypes of heat pumps in HERO are:

1. Air source reverse cycle - heating optimised
2. Air source reverse cycle - cooling optimised
3. Ground source reverse cycle - heating optimised
4. Ground source reverse cycle - cooling optimised
5. Water source reverse cycle - heating optimised
6. Water source reverse cycle - cooling optimised

For each heat pump, the electrical consumption is calculated according to the following equation (monthly base):

$$W_{HPUMP} = \frac{\dot{Q}_{dem}}{COP\ or\ EER} \quad \textbf{(2.17)}$$

Where:

$\dot{Q}_{dem}$ ⇨ Total heating and/or cooling demand for all the zones it serves

COP ⇨ Coefficient of performance

EER ⇨ Energy efficiency ratio

As COP or EER are not mandatory fields in the iSERV spreadsheet, in the case that are missing, a value of 2.5 for heating and 3 for cooling are supposed. No distinction is made according to heat source (e.g. air, water, ground).

If more than one heat pump serving the same zone exist, then loads are divided in equal parts.

2.7.2.8 Heat Recovery

The existing subtypes of heat recovery components in HERO are:

1. Heat pipe (DX heat recovery)
2. Plate Heat Exchanger (Air/Air) with/without by-pass
3. Recuperator Heat Recovery
4. Rotary Wheel Heat Exchanger sensible/sensible + latent
5. Run-around-coil Heat Recovery (Air/Water)

For each heat recovery component, the electrical consumption is calculated according to the following equation (monthly base):

$$W_{HREC} = \Delta t \cdot \dot{W}_{HREC,n} \quad \textbf{(2.18)}$$

Where:

Δt ⇨ Monthly mechanical ventilation operation time

$\dot{W}_{HREC,n}$ ⇨ Nominal power

2.7.2.9 Heat Rejection

The existing subtypes of heat rejection components in HERO are:

1. Air condensers
2. Closed Circuit Cooling Towers
3. Dry cooler
4. Evaporation Cooler
5. Forced air condensers
6. Mechanical Draft Towers
7. Natural Draft Towers
8. Open Circuit Cooling Towers

For each heat rejection component, the electrical consumption is calculated according to the following equation (monthly base):

$$W_{HREJ} = \Delta t \cdot \dot{W}_{HREJ,n} \qquad \textbf{(2.19)}$$

Where:

Δt ⇨ Monthly indoor cooling operation time corrected by the fraction of month of the cooling season

$\dot{W}_{HREJ,n}$ ⇨ Nominal power

2.7.2.10 Humidifiers

The existing subtypes of humidifiers components in HERO are:

1. Air Washer
2. Electric
3. Gas
4. Steam
5. Vaporizing
6. Waste heat
7. Water Spray

For each humidifier component, the electrical consumption is calculated according to the following equation (monthly base):

$$W_{HUM} = \Delta t \cdot \dot{W}_{HUM,n} \qquad \textbf{(2.20)}$$

Where:

Δt	⇨	Monthly indoor heating operation time corrected by the fraction of month of the heating season
$\dot{W}_{HUM,n}$	⇨	Nominal power

2.7.2.11 Pumps

The existing subtypes of pumps components in HERO are:

1. Chilled water primary pumps
2. Chilled water secondary pumps
3. Condenser water pumps
4. DHW primary pumps
5. DHW secondary (circulation) pumps
6. Hot water primary pumps
7. Hot water secondary pumps

For each pump component, the electrical consumption is calculated according to the following equation (monthly base):

$$W_{PUMP} = \Delta t \cdot \dot{W}_{PUMP,n} \quad \textbf{(2.21)}$$

Where:

Δt	⇨	1. The maximum between the monthly indoor heating operation time and monthly mechanical ventilation operation time; corrected by the fraction of month of the heating season 2. The maximum between the monthly indoor cooling operation time and monthly mechanical ventilation operation time; corrected by the fraction of month of the cooling season
$\dot{W}_{PUMP,n}$	⇨	Nominal power

2.7.2.12 Storage Systems

The existing subtypes of storage systems in HERO are:

1. Cold water buffer tank
2. Hot water buffer tank
3. Ice storage tank
4. PCM (phase change material)

For each storage system, the electrical consumption is calculated according to the following equation (monthly base):

$$W_{STOR} = \Delta t \cdot \dot{W}_{STOR,n} \quad \textbf{(2.22)}$$

Where:

Δt ⇨
1. The maximum between the monthly indoor heating operation time and monthly mechanical ventilation operation time; corrected by the fraction of month of the heating season
2. The maximum between the monthly indoor cooling operation time and monthly mechanical ventilation operation time; corrected by the fraction of month of the cooling season

$\dot{W}_{STOR,n}$ ⇨ Nominal power

2.7.2.13 Terminal Units

The existing subtypes of terminal units in HERO are:

1. Active chilled beams
2. Active heated beams
3. Chilled ceiling panels
4. Chilled pipes in fabric : - 2or 4 tubes
5. DX indoor unit
6. Electric radiators
7. Fan Coils – 2 or 4 tubes
8. Heated ceiling panels
9. Induction units – 2 or 4 tubes
10. Passive chilled beams
11. Passive heated beams
12. Under floor heating
13. VRV/VRF indoor unit
14. Water radiators

For each terminal unit, the electrical consumption is calculated according to the following equation (monthly base):

$$W_{TU} = \Delta t \cdot \dot{W}_{TU,n} \qquad \textbf{(2.23)}$$

Where:

Δt ⇨
1. The maximum between the monthly indoor heating operation time and monthly mechanical ventilation operation time; corrected by the fraction of month of the heating season
2. The maximum between the monthly indoor cooling operation time and monthly mechanical ventilation operation time; corrected by the fraction of month of the cooling season

$\dot{W}_{TU,n}$ ⇨ Nominal power

2.7.2.14 Total HVAC Consumption

Once the monthly electrical consumption is calculated for each component, a sum is performed in order to obtain the whole HVAC system(s) electrical consumption.

3 DEFINITION AND EVALUATION OF ECOs

In the previous chapter, a review of the whole code of the core model has been provided. In this one, a detailed description about how it is used to build each ECO is presented.

When evaluating a desired ECO, what the model code does is to calculate the HVAC and whole building electrical consumption for 4 different scenarios:

1. Case 0 (i.e. reference case): The building as it is. Electrical consumption is calculated with respect to the data compiled in HERO
2. Case minimum: First proposed scenario for which the ECO is evaluated. Minimum means a conservative scenario
3. Case average: Second proposed scenario for which the ECO is evaluated, that corresponds to an average improvement scenario
4. Case maximum: Third proposed scenario for which the ECO is evaluated. Maximum corresponds to the most optimistic scenario

Figure 7 shows a general scheme of the ECO evaluation process.

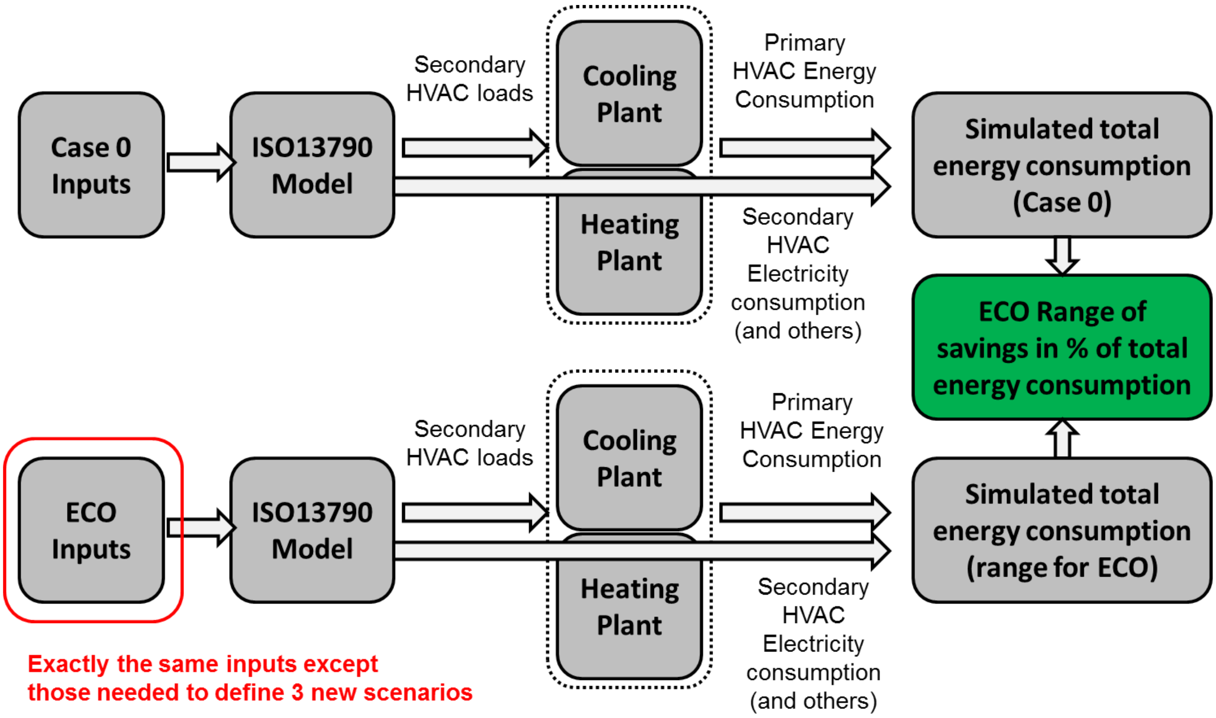

Figure 7: General Scheme of ECOs evaluation

According to the Matlab syntax, each ECO correspond to function as:

```
[MonthHVAC,YearHVAC,YearHVACm2,MonthWBUILD,YearWBUILD,YearWBUILDm2,PerYearWBUI
LD,info_user]=ECO_X_FS(jdbcConnStr,buildingId)
```

The summary of inputs and outputs is provided in Table 5. The first two variables correspond to inputs and the remaining ones to outputs.

Table 5 – Summary of inputs and outputs

Variable	Description	Unit	Element type & size
jdbcConnStr	String variable which connects the Matlab code with the HERO database	-	String
buildingId	Unique Id assigned by HERO to each building	-	Double - 1x1
MonthHVAC	Monthly electrical HVAC consumption	[kWh/month]	Double - 12x4
YearHVAC	Annual electrical HVAC consumption	[kWh/year]	Double - 1x4
YearHVACm2	Annual electrical HVAC consumption per m^2	[kWh/year]	Double - 1x4
MonthWBUILD	Monthly whole-building electrical consumption	[kWh/month]	Double - 12x5
YearWBUILD	Annual whole-building electrical consumption	[kWh/year]	Double - 1x5
YearWBUILDm2	Annual whole-building electrical consumption per m^2	[kWh/year]	Double - 1x5
PerYearWBUILD	Percentage of savings over the whole building consumption	[kWh/year]	Double - 1x3
Info_user	Vector containing information to the user about assumptions, warning and errors	-	String

For HVAC consumption outputs, each column corresponds to: case 0, minimum, average and maximum respectively.

For whole building consumption outputs, each column corresponds to: metered data, case 0, minimum, average and maximum respectively. If metered data doesn't exist, then the first column is filled by *NaN* elements.

In the case of percentage of savings the 3 columns correspond to case minimum, average and maximum respectively.

3.1 ECO O2.2 - Shut off AC equipment when not needed

System on which this ECO may apply

Air Conditioned equipment, including pumps when the cold generator includes pumps.

Considered Actions

This ECO mainly aims to shut off A/C equipment during:

- ➔ Weekday's unoccupied periods (night operation)
- ➔ Weekends

Another action would be to shut off A/C equipment during winter season. This condition is already implemented in the base code.

Tools Used

Model based on *ISO 13790*

Preconditions: check & validation

The model checks whether the occupancy period is lower than conditioned one (heating and cooling) for weekdays and whether A/C equipment operates during weekends. If either of them is met, the code calculates the difference of daily operating hours for weekdays (Δt_{wd}) and the daily operating hours for weekends (Δt_{we}). This calculation is done for heating and cooling schedules.

Description and Assumptions

Once calculated the potential reduction of operation time, the new periods are defined as:

Table 6 : New periods definition for ECO O2.2

	Daily operation time	Units
Weekdays	$t_{wd,new} = t_{wd,case0} - f_{\Delta t} \cdot \Delta t_{wd}$	[h/day$_{wd}$]
Weekends	$t_{we,new} = t_{we,case0} - f_{\Delta t} \cdot \Delta t_{we}$	[h/day$_{we}$]
Average Monthly	$t = \frac{(5 \cdot t_{wd} + 2 \cdot t_{we})}{7}$	[h/day]

Related to the scenarios definition, the factor $f_{\Delta t}$ is assumed as follows: $f_{\Delta t} = 1/3$ for the case minimum, $f_{\Delta t} = 2/3$ for the case average and $f_{\Delta t} = 1$ for the case maximum.

The procedure is repeated twice in order to update heating and cooling operation time for each scenario.

These changes also affect the definition of ventilation schedule.

Remark:
The number of reduction hours can vary significantly depending on the defined operation of case 0.

Reference:
O2.# GENERAL HVAC SYSTEM / O2.2 Shut off A/C equipment when not needed. Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems – HARMONAC

3.2 ECO O2.3 - Shut off auxiliaries when not required

System on which this ECO may apply

AHU fans, pumps and terminal units in general.

Considered Actions

This ECO mainly aims to shut off auxiliaries during unoccupied period.

Tools Used

Model based on *ISO 13790*

Preconditions: check & validation

The model checks whether the occupancy period is lower than conditioned one (heating and cooling) for weekdays and weekends. If either of them is met: the code calculates the difference of daily operating hours for weekdays (Δt_{wd}) and the difference of daily operating hours for weekends (Δt_{we}). This calculation is done for heating and cooling schedules.

Description and Assumptions

Once calculated the potential reduction of operation time, the new periods are defined as:

Table 7 : New periods definition for ECO O2.3

	Daily operation time	Units
Weekdays	$t_{wd,new} = t_{wd,case0} - f_{\Delta t} \cdot \Delta t_{wd}$	[h/day$_{wd}$]
Weekends	$t_{we,new} = t_{we,case0} - f_{\Delta t} \cdot \Delta t_{we}$	[h/day$_{we}$]
Average Monthly	$t = \frac{(5 \cdot t_{wd} + 2 \cdot t_{we})}{7}$	[h/day]

Related to the scenarios definition, it is done assuming: $f_{\Delta t} = 1/3$ for the case minimum, $f_{\Delta t} = 2/3$ for the case average and $f_{\Delta t} = 1$ for the case maximum.

The procedure is repeated twice in order to update heating and cooling operation time for each scenario.

These changes also affect the definition of ventilation schedule.

Remark :

The number of reduction hours can vary a significantly depending on the defined operation of case 0.

Reference :

O2.# GENERAL HVAC SYSTEM / O2.3 Shut off auxiliaries when not required. Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems – HARMONAC

3.3 ECO E1.1 - Install window film or tinted glass

System on which this ECO may apply

Window and glass with/without shading device.

Considered Actions

Install window film or tinted glass.

Tools used

Model based on *ISO 13790*

Preconditions: check & validation

No preconditions. This ECO may be evaluated over the whole data base.

Description and assumptions

As the iSERV spreadsheet does not provide any data about geometry, envelope or orientation, the following assumptions have been made:

- ➔ Window to wall ratio = 0.5 (each zone counts with 4 external wall surfaces)
- ➔ Window to frame ratio = 0.95
- ➔ g-value is estimated according to the construction (or renovation) year - See Table 8
- ➔ For evaluating ECO's scenarios, a value of 0.9 x g_{case0}, 0.7 x g_{case0} and 0.5 x g_{case0} is assumed for case minimum, average and maximum respectively.

Table 8 – g-value according to construction (or renovation) year. Case 0, minimum, average and maximum, respectively.

Construction year	g-values Case 0 [-]	Case Minimum [-]	Case Average [-]	Case Maximum [-]
≤ 1970	0.85	0.77	0.60	0.43
≤ 1984	0.85	0.77	0.60	0.43
≤ 1996	0.7	0.63	0.49	0.35
≤ 2006	0.7	0.63	0.49	0.35
≤ 2010	0.7	0.63	0.49	0.35
> 2010	0.6	0.54	0.42	0.30

Reference :

E1.# Solar gain reduction / daylight control improvement / E1.1 Install window film or tinted glass. Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems – HARMONAC

3.4 ECO O3.1 - Shut off chiller plant when not required

System on which this ECO may apply

Chiller with/without a time controller.

Considered Actions

This ECO mainly aims to shut off chiller plant during unoccupied period.

Tools Used

Model based on *ISO 13790*

Preconditions: check & validation

The model checks whether the occupancy period is lower than cooling one for weekdays and weekends. If either of them is met: the code calculates the difference of daily operating hours for weekdays (Δt_{wd}) and the difference of daily operating hours for weekends (Δt_{we}). This calculation is done for heating and cooling schedules.

Description and Assumptions

Once calculated the potential reduction of operation time, the new periods are defined as:

Table 9 : New period definition for ECO O3.1

	Daily operation time	Units
Weekdays	$t_{wd,new} = t_{wd,case0} - f_{\Delta t} \cdot \Delta t_{wd}$	[h/day$_{wd}$]
Weekends	$t_{we,new} = t_{we,case0} - f_{\Delta t} \cdot \Delta t_{we}$	[h/day$_{we}$]
Average Monthly	$t = \frac{(5 \cdot t_{wd} + 2 \cdot t_{we})}{7}$	[h/day]

Related to the scenarios definition, it is done assuming: $f_{\Delta t} = 1/3$ for the case minimum, $f_{\Delta t} = 2/3$ for the case average and $f_{\Delta t} = 1$ for the case maximum.

The procedure is done for each scenario.

These changes also affect the definition of ventilation schedule.

Remark :

The number of reduction hours can vary a significantly depending on the defined operation of case 0.

Reference :

O3.# Cooling equipment / O3.1 Shut chiller plant off when not required. Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems – HARMONAC

3.5 ECO E4.6 - Replace lighting equipment with low consumption type

System on which this ECO may apply

Lighting equipment.

Considered Actions

To replace high consumption lighting equipment with low consumption type. High consumption lighting equipment are mainly halogen lamp and incandescent lamp.

Tools used

Model based on *ISO 13790*

Preconditions: check & validation

No preconditions. This ECO may be evaluated over the whole data base.

Description and assumptions

As the iSERV spreadsheet does not provide any data about lighting equipment, the following assumptions have been made:

- ➔ Lighting power density (LPD) is estimated according to the sector definition used for the ECOs - See Table 10
- ➔ For evaluating ECO's scenarios, a value of 0.9 x LPD_{case0}, 0.7 x LPD_{case0} and 0.5 x LPD_{case0} is assumed for case minimum, average and maximum respectively.

Table 10 – Lighting power density according to sector definition. Case 0, minimum, average and maximum, respectively.

	Lighting Power Density			
Sector in ECO	**Case 0 [W/m²]**	**Case Minimum [W/m²]**	**Case Average [W/m²]**	**Case Maximum [W/m²]**
Offices < 1500 m²	10.8	9.72	7.56	5.40
Offices >= 1500 m²	10.8	9.72	7.56	5.40
Education	15.1	13.59	10.57	7.55
Hospitals	13	11.70	9.10	6.50
Catering	10.8	9.72	7.56	5.40
Trade	16.2	14.58	11.34	8.10
Assembly	15.1	13.59	10.57	7.55
Accommodation	7.6	6.84	5.32	3.80
Sports	15.1	13.59	10.57	7.55
Large space	15	13.50	10.50	7.50

Reference :

Values are based on standardized assumptions for US non-residential buildings (Stocki et al., 2007) and ISO13790 – Annex G standard input data.

E4.# Other actions aimed at load reduction/ E4.6 Replace lighting equipment with low consumption type. Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems – H RMONAC

3.6 ECO 4.5 - Replace electrical equipment with Energy Star or low consumption types

System on which this ECO may apply

Office equipment such as: e.g. computers and monitors, printers, fax machines & mailing machines, scanners, copiers. This ECO generates savings for office equipment electric consumption but at the same time increase heating demand and decrease cooling demand (Efficient equipment give off less heat).

Considered Actions

To replace highest consumption material with low consumption types.

Tools used

Model based on *ISO 13790*

Preconditions: check & validation

No preconditions. This ECO may be evaluated over the whole data base.

Description and assumptions

As the iSERV spreadsheet does not provide any data about office equipment (computers and monitors, printers, fax machines & mailing machines, scanners, copiers, etc.), the following assumptions have been made:

- ➔ Appliances power density (APD) is estimated according to the sector definition used for the ECOs - See Table 11
- ➔ For evaluating ECO's scenarios, a value of 0.9 x APD_{case0}, 0.7 x APD_{case0} and 0.5 x APD_{case0} is assumed for case minimum, average and maximum respectively.

Table 11 –Appliances power density according to sector definition. Case 0, minimum, average and maximum, respectively.

Sector in ECO	Appliances Power Density			
	Case 0 [W/m^2]	Case Minimum [W/m2]	Case Average [W/m2]	Case Maximum [W/m2]
Offices < 1500 m2	8.1	7.29	5.67	4.05
Offices >= 1500 m2	8.1	7.29	5.67	4.05
Education	10.1	9.09	7.07	5.05
Hospitals	23.7	21.33	16.59	11.85
Catering	6.9	6.21	4.83	3.45
Trade	4.3	3.87	3.01	2.15
Assembly	2.6	2.34	1.82	1.30
Accommodation	4.8	4.32	3.36	2.40
Sports	2.6	2.34	1.82	1.30
Large space	**5**	**4.50**	**3.50**	**2.50**

Reference :

Values are based on standardized assumptions for US non-residential buildings (Stocki et al., 2007) and ISO13790 – Annex G standard input data.

E4.# Other actions aimed at load reduction/ E4.5 Replace electrical equipment with Energy Star or low consumption types. Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems - HARMONAC

3.7 ECO P2.6 - Replace or upgrade cooling equipment and heat pump

System on which this ECO may apply

Systems comprising any heat pump or cold generator as component.

Considered Actions

- ➔ To replace inefficient equipment with new efficient type
- ➔ To upgrade cooling equipment/heat pump

Tools used

Model based on *ISO 13790*

Preconditions: check & validation

This ECO may be evaluated over any system that counts with at least one: all in one system, cold generator or heat pump.

Description and assumptions

In order to evaluate the 3 scenarios, the following assumptions have been made:

- ➔ For evaluating ECO's scenarios, a value of 1.05 x $(EER\ or\ COP)_{case0}$, 1.15 x $(EER\ or\ COP)_{case0}$ and 1.25 x $(EER\ or\ COP)_{case0}$ is assumed for case minimum, average and maximum respectively
- ➔ This upgrading factor is applied to any all in one system, cold generator or heat pump present in any system
- ➔ If COP or EER has not been provided, a value of 2.5 and 3 are assumed respectively for the case 0

Reference :

P2.# Cooling equipment /Free Cooling/ P2.6 Replace or upgrade cooling equipment and heat pump. Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems - HARMONAC

3.8 ECO O4.19 - Switch off circulation pumps when not required

System on which this ECO may apply

Circulation pumps.

Considered Actions

This ECO mainly aims to switch off circulations pumps during unoccupied period.

Tools Used

Model based on *ISO 13790*

Preconditions: check & validation

The model checks whether the occupancy period is lower than conditioned one (heating and cooling) for weekdays and weekends. If either of them is met: the code calculates the difference of daily operating hours for weekdays (Δt_{wd}) and the difference of daily operating hours for weekends (Δt_{we}). This calculation is done for heating and cooling schedules.

Description and Assumptions

Once calculated the potential reduction of operation time, the new periods are defined as:

Table 12 : New period definition for ECO O4.19

	Daily operation time	Units
Weekdays	$t_{wd,new} = t_{wd,case0} - f_{\Delta t} \cdot \Delta t_{wd}$	[h/day$_{wd}$]
Weekends	$t_{we,new} = t_{we,case0} - f_{\Delta t} \cdot \Delta t_{we}$	[h/day$_{we}$]
Average Monthly	$t = \frac{(5 \cdot t_{wd} + 2 \cdot t_{we})}{7}$	[h/day]

Related to the scenarios definition, it is done assuming: $f_{\Delta t} = 1/3$ for the case minimum, $f_{\Delta t} = 2/3$ for the case average and $f_{\Delta t} = 1$ for the case maximum.

The procedure is repeated twice in order to update heating and cooling operation time for each scenario.

These changes also affect the definition of ventilation schedule.

The resulting new operation time are only applied to circulation pumps.

Remark :

The number of reduction hours can vary a significantly depending on the defined operation of case 0.

Reference

O4.# Fluid (air and water) handling and distribution / O4.19 Switch off circulation pumps when not required.
Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems – HARMONAC

3.9 ECO O2.7 - Sequence central heating and cooling

System on which this ECO may apply

HVAC System.

Considered Actions

Central control of heating and cooling generators and associated water circuit (winter summer mode).

Tools Used

Model based on *ISO 13790*

Preconditions: check & validation

No preconditions. This ECO may be evaluated over the whole data base.

Description and Assumptions

One of the main outputs of the approach proposed by ISO 13790 are the length of heating and cooling season (for system running hours) affecting the energy use and auxiliary energy of season-length-dependent technical building systems for heating, cooling and ventilation.

For the reference case, these values are estimated by the thermal balance in each zone, providing a value between 0 and 1 which represent the fraction of month that indoor heating or cooling is needed.

The approach used for implementing this ECO is to set to zero the heating and cooling loads for those month for which heating and cooling length season is lesser or equal than a specified fraction of time. These values are shown in Table 13.

Table 13 – Minimum heating and cooling length season values. Case 0, minimum, average and maximum, respectively.

	Minimum Heating and Cooling Length Season Values			
	Case 0 [-]	Case Minimum [-]	Case Average [-]	Case Maximum [-]
Heating	0	0.1	0.2	0.3
Cooling	0	0.1	0.2	0.3

This reduction on heating and cooling season length also impacts on associated auxiliaries equipment.

Reference :

O2.# General HVAC system / O2.7 Sequence central heating and cooling. Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems – HARMONAC

3.10 ECO E2.4 - Correct excessive envelope air leakage

System on which this ECO may apply

Entire building envelope.

Considered Actions

To modify building envelope (suppressing gaps, introducing calibrated air inlets).

Tools used

Model based on *ISO 13790*

Preconditions: check & validation

No preconditions. This ECO may be evaluated over the whole data base.

Description and assumptions

As the iSERV spreadsheet does not provide any data about geometry, envelope or orientation, the following assumptions have been made:

- ➔ Infiltration air change rate (ACH) is estimated according to the construction (or renovation) year - See Table 14
- ➔ For evaluating ECO's scenarios, a value of (ACH_{case0}-0.1), (ACH_{case0}-0.2) and (ACH_{case0}-0.3) is assumed for case minimum, average and maximum respectively.

Table 14 –Infiltration air change according to construction (or renovation) year. Case 0, minimum, average and maximum, respectively.

Construction year	Infiltration Air Change Rate			
	Case 0 [1/h]	Case Minimum [1/h]	Case Average [1/h]	Case Maximum [1/h]
≤ 1970	0.85	0.77	0.60	0.43
≤ 1984	0.85	0.77	0.60	0.43
≤ 1996	0.7	0.63	0.49	0.35
≤ 2006	0.7	0.63	0.49	0.35
≤ 2010	0.7	0.63	0.49	0.35
> 2010	0.6	0.54	0.42	0.30

Reference :

E2.# Ventilation / Air movement / air leakage improvement /E2.4 Correct excessive envelope air leakage. Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems – HARMONAC

3.11 ECO O4.1 - Consider modifying the supply air temperature

System on which this ECO may apply

Mechanical ventilation system.

Considered Actions

To control ventilation supply temperature according to weather conditions.

Tools used

Model based on *ISO 13790*

Preconditions: check & validation

This ECO may be evaluated as “conditioned” mechanical ventilation exists.

Description and assumptions

As the iSERV spreadsheet does not provide any data about ventilation control, a control law proposed in Figure 8 is applied.

It must be mentioned that the code makes difference of two types of conditioned mechanical ventilation: all air and air and water systems.

For all air systems, the supply air temperature is equal to 13°C all over the year (case 0) and for air and water systems, the supply air temperature is equal to 18°C all over the year (case 0).

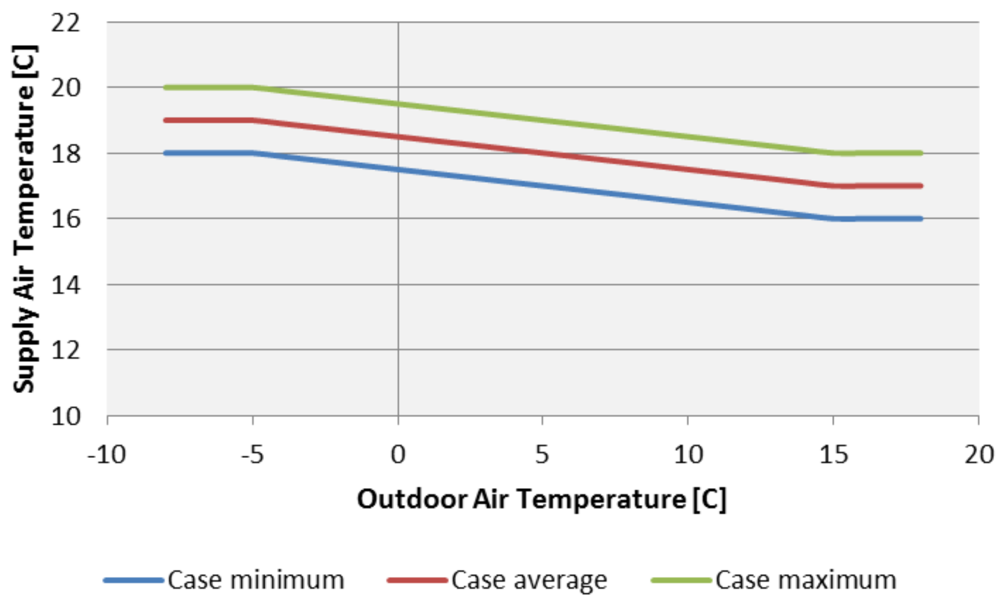

Figure 8: Supply air temperature in function of outdoor air temperature. Control law used for air and water systems.

Table 15 – Summary of parameters used to build the operation curve

	Outdoor Temperature [C]	Supply Air Temperature Case 0 [C]	Case minimum [C]	Case average [C]	Case maximum [C]
All air systems	≤-5	13	13	14	15
	≥15	13	11	12	13
Air and water systems	≤-5	18	18	19	20
	≥15	18	16	17	18

References :

O4.# Fluid (air and water) handling and distribution /O4.1 Consider modifying the supply air temperature. Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems – HARMONAC

3.12 ECO E1.3 - Optimize control of blinds

System on which this ECO may apply

Movable shading device. This ECO affects heating and cooling demand, but also the electric demand for artificial lighting.

Considered Actions

To operate shading device with outdoor illuminance control.

Tools used

Model based on *ISO 13790*

Preconditions: check & validation

No preconditions. This ECO may be evaluated over the whole data base.

Description and assumptions

As the iSERV spreadsheet does not provide any data about geometry, envelope or orientation, the following assumptions have been made:

- ➔ Window to wall ratio = 0.5 (each zone counts with 4 external wall surfaces)
- ➔ Window to frame ratio = 0.95
- ➔ g-value is estimated according to the construction year
- ➔ The operation of blinds is based on the curve shown in Figure 9
- ➔ As no outdoor illuminance is available, a conversion factor 100 lux/W/m^2 is assumed

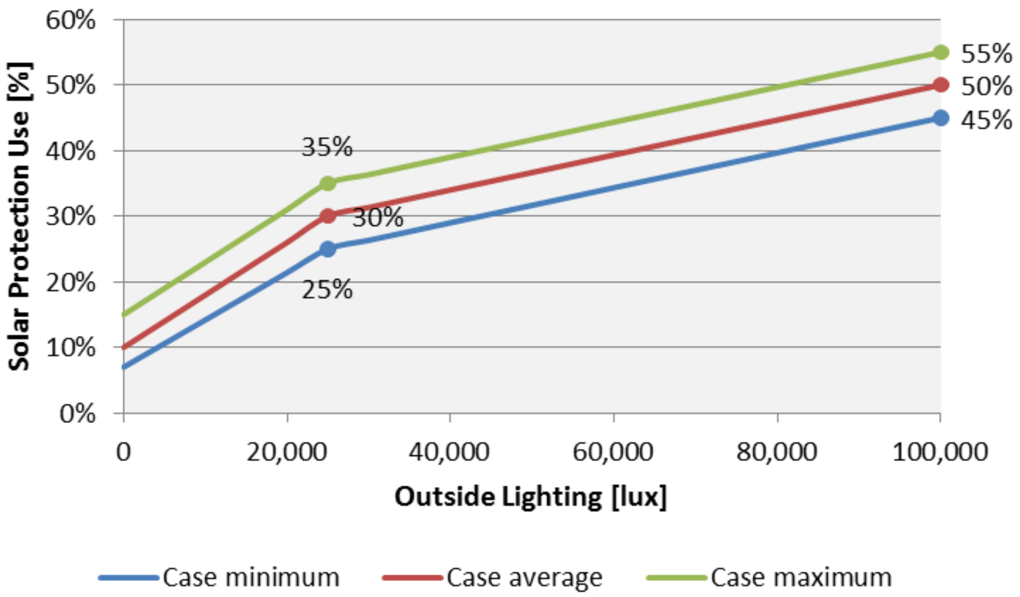

Figure 9: Blind position according to outdoor illuminance level

Table 16 – Summary of parameters used to build the operation curve

	Solar Protection Use			
Outdoor Illuminance [lux]	**Case 0 [%]**	**Case minimum [%]**	**Case average [%]**	**Case maximum [%]**
0	0	7	10	15
25,000	0	25	30	35
100,000	0	45	50	55

References :

E1.# Solar gain reduction / daylight control improvement/E1.3 Optimize control of blinds. Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems – HARMONAC

3.13 ECO P3.9 - Introduce exhaust air heat recovery

System on which this ECO may apply

HVAC System.

Considered Actions

To install heat recovery ventilation controlled by supply temperature, i.e. to introduce an air/air heat exchanger and a bypass forward HVAC equipment

Tools used

Model based on *ISO 13790*

Preconditions: check & validation

This ECO may be evaluated as mechanical ventilation exists.

Description and assumptions

In order to evaluate the 3 scenarios, the following assumptions have been made:

- ➔ Heat recovery efficiency (HRE) is estimated according to the construction (or renovation) year - See Table 17
- ➔ For evaluating ECO's scenarios, a value of 1.1 x HRE_{case0}, 1.2 x HRE_{case0} and 1.3 x HRE_{case0} is assumed for case minimum, average and maximum respectively.
- ➔ In the case that efficiency is equal to zero for the case 0, the values corresponding to buildings constructed up to 1996 is used - See Table 17

Table 17 – Heat recovery efficiency according to construction (or renovation) year. Case 0, minimum, average and maximum, respectively.

	Heat Recovey Efficiency			
Construction year	Case 0 [-]	Case Minimum [-]	Case Average [-]	Case Maximum [-]
≤ 1970	0	0.33	0.36	0.39
≤ 1984	0	0.33	0.36	0.39
≤ 1996	0.3	0.33	0.36	0.39
≤ 2006	0.45	0.50	0.54	0.59
≤ 2010	0.6	0.66	0.72	0.78
> 2010	0.7	0.77	0.84	0.91

Reference :

P3.# Air Handling / Heat recovery / Air distribution / P3.9 Introduce exhaust air heat recovery. Appendix 3: Energy Conservation Opportunities for Air Conditioning Systems – HARMONAC

4 Methodology based on ISO standard 13790

This Chapter explains in details the approach used by ISO 13790 to calculate heating and cooling loads as well as the evaluation of the accuracy of the model by means of a theoretical exercise.

4.1 ISO 13790 – Model Description

The ISO13790 standard proposes different types of calculation procedure (i.e. monthly or seasonal, simple hourly and detailed simulation). However, this procedure is based on a set of common assumptions and basic physical data (e.g. environment, conditions, user behaviour).

For the iSERV ECO simulation tool, the type of method selected is the "seasonal or monthly method". Indeed this method enables a both simple and accurate calculation of the energy needs for heating and cooling at a zone/building level before and after modifications (ECOs).

For each zone and each simulated month (calculation step), the building energy need for space heating and cooling is calculated using a quasi-steady-state heat balance method. Dynamic effects are taken into account by introducing correlation factors.

The building energy balance may also include energy recovered in the building from various sources, such as recovered ventilation heat losses and recoverable losses from heating and cooling system.

For heating, a utilization factor for the internal and solar heat gains takes into account the fact that internal and solar heat gains influence only partly the decrease of energy need for heating. The rest leading to an undesired increased of the internal temperature above the set-point. This approach is described in the following equations:

- ➔ Energy need for heating = Total heat losses – usable fraction of internal gains

$$Q_{h_{nd_{cont}}} = Q_{h_{ht}} - \eta_{h_{gn}} * Q_{h_{gn}} \qquad \textbf{(4.1)}$$

- ➔ Internal gains = Occupancy + Lighting + Appliances + Solar gains

$$Q_{h_{gn}} = f_{appl} * Q_{appl} + f_{occ} * Q_{occ} + f_{light} * Q_{light} + Q_{sol} \qquad \textbf{(4.2)}$$

A similar method is used for cooling. It defines a utilization factor for the transmission and ventilation heat transfer. This one takes into account the fact that only part of this heat transfer is utilized to decrease the cooling needs. Indeed the "non-used" transmission and ventilation heat transfers occur during periods or intervals (e.g. nights) when they have no effect on the cooling needs occurring during other periods or moments (e.g. days).

- ➔ Energy need for cooling = Internal gains – usable fraction of heat losses

$$Q_{c_{nd_{cont}}} = Q_{c_{gn}} - \eta_{c_{is}} * Q_{c_{ht}} \qquad \textbf{(4.3)}$$

- ➔ Internal gains = Occupancy + Lighting + Appliances + Solar gains

$$Q_{h_{gn}} = f_{appl} * Q_{appl} + f_{occ} * Q_{occ} + f_{light} * Q_{light} + Q_{sol} \qquad \textbf{(4.4)}$$

➔ Total heat losses = Transmission + Ventilation

$$Q_{h_{ht}} = Q_{h_{tr}} + Q_{h_{ve}} \quad \textbf{(4.5)}$$

$$Q_{c_{ht}} = Q_{c_{tr}} + Q_{c_{ve}} \quad \textbf{(4.6)}$$

The effect of thermal inertia in the case of intermittent heating, intermittent cooling or switch-off is taken into account separately (please see the following sub section "*Internal condition*"). Heating and cooling in the same month can also be established by calculating 12 months heating mode and 12 months cooling mode, each with own parameters values (e.g. ventilation, heat recovery). The calculation methods for each member of the equations here above are described in the following sub-sections together with other important input parameters.

4.1.1 Internal condition

They are 2 different modes for heating and cooling considered:

➔ Continuous : the set-point temperatures for the calculation in this mode will be the set-point temperatures for normal heating and cooling:

$$T_{i_{set_h}} = T_{i_{set_{h1}}} \quad \textbf{(4.7)}$$

$$T_{i_{set_c}} = T_{i_{set_{c1}}} \quad \textbf{(4.8)}$$

➔ Quasi-continuous heating and/or cooling at constant set-point. In this case the heating and cooling shall be considered as continuous heating and cooling with adjusted set-point temperature of mode A or mode B applies.

Mode A:

1. If the set-point temperature variations between normal heating or cooling and reduce heating or cooling are less than 3K and/or
2. if the time constant of the building (τ) is less than 0.2 times the duration of the shortest reduced heating period or cooling period.

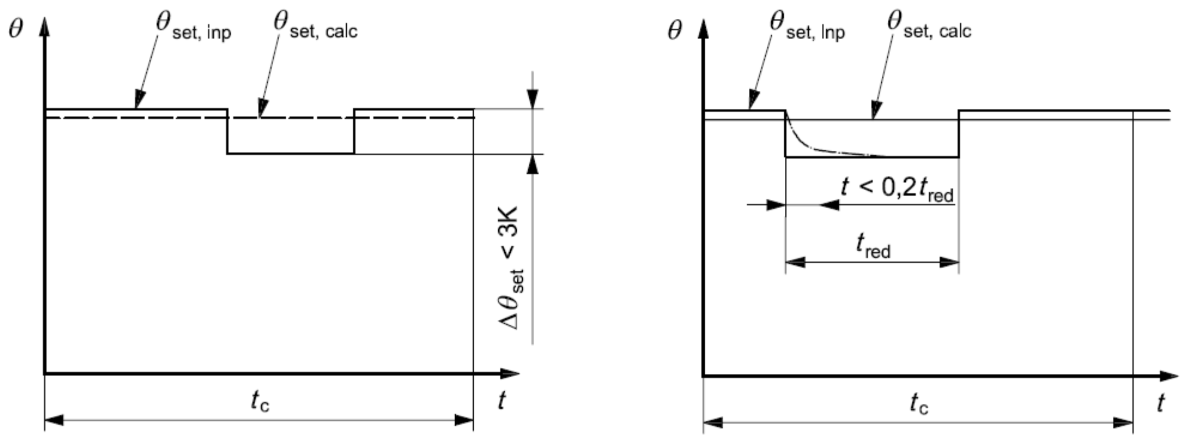

Figure 10 – Example of quasi-continuous heating. Mode A.

➔ The set-point temperatures for the calculation is the time average of the set-point temperatures for heating and cooling:

$$T_{i_{set_h}} = \frac{5 * \frac{t_{set_{wd}} * T_{i_{set_{h1}}} + (24 - t_{set_{wd}}) * T_{i_{set_{h2}}}}{24} + 2 * \frac{t_{set_{we}} * T_{i_{set_{h1}}} + (24 - t_{set_{we}}) * T_{i_{set_{h2}}}}{24}}{7} \quad \textbf{(4.9)}$$

$$T_{i_{set_c}} = \frac{5 * \frac{t_{set_{wd}} * T_{i_{set_{c1}}} + (24 - t_{set_{wd}}) * T_{i_{set_{c2}}}}{24} + 2 * \frac{t_{set_{we}} * T_{i_{set_{c1}}} + (24 - t_{set_{we}}) * T_{i_{set_{c2}}}}{24}}{7} \quad \textbf{(4.10)}$$

Mode B:

If the time constant of the building is greater than three times the duration of the longest reduced heating period / cooling period.

➔ The set-point temperatures for the calculation in this mode will be the set-point temperatures for normal heating and cooling:

$$T_{i_{set_h}} = T_{i_{set_{h1}}} \quad \textbf{(4.11)}$$

$$T_{i_{set_c}} = T_{i_{set_{c1}}} \quad \textbf{(4.12)}$$

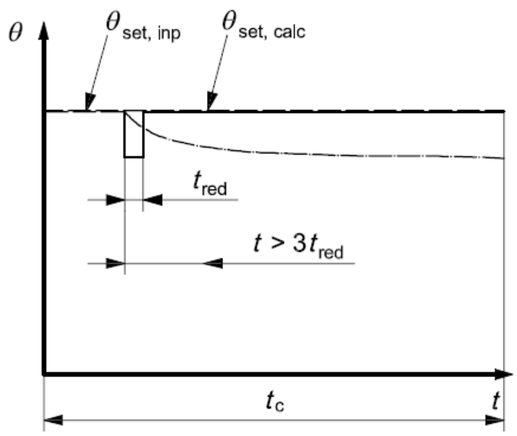

Figure 11 – Example of quasi-continuous heating. Mode B.

4.1.2 Correction for intermittency

A correction is applied to heating and cooling calculated need when the intermittent heating or cooling does not fulfill the conditions of Mode A or Mode B.

$$Q_{h_{nd}} = a_{h_{red}} * Q_{h_{nd_{cont}}} \quad \textbf{(4.13)}$$

$$Q_{c_{nd}} = a_{c_{red}} * Q_{c_{nd_{cont}}} \quad \textbf{(4.14)}$$

This correction is based on the "$a_{h_{red}}$"/"$a_{c_{red}}$" factor which is a dimensionless reduction factor for intermittent heating/cooling given by the following equations:

$$a_{h_{red1}} = 1 - b_{h_{red}} * \left(\frac{tau_{h_0}}{tau_h}\right) * gamma_h * \left(1 - f_{h_{hr}}\right) \quad \textbf{(4.15)}$$

$$a_{c_{red1}} = 1 - b_{c_{red}} * \left(\frac{tau_{c_0}}{tau_c}\right) * gamma_c * \left(1 - f_{c_{day}}\right) \quad \textbf{(4.16)}$$

where $b_{h_{red}}$ and $b_{c_{red}}$ are empirical correlation factors,

γ_h and γ_c is the heat balance ratio for the heating/cooling mode

$f_{h_{hr}}$ is the fraction of the number of hours in a week with a normal heating set-point (no reduced set-point or switch off),

$f_{c_{day}}$ is the fraction of the number of days in the week with, at least during daytime, normal cooling set-point (no reduced set-point or switch off),

4.1.3 Heat transfer by transmission

The total heat transfer by transmission, Q_{tr}, is calculated for each month and for each zone by the equations:

- ➔ For heating : $Q_{h_{tr}} = H_{tr} * \left(T_{i_{set_h}} - T_{e_m}\right) * \Delta t$
- ➔ For cooling : $Q_{c_{tr}} = H_{tr} * \left(T_{i_{set_c}} - T_{e_m}\right) * \Delta t$

In the ISO 13790, the overall heat transfer coefficient by transmission H_{tr} is determined according to all the ISO 13789 specific methods. These methods require a lot of information in terms of geometrical and envelope characteristics. This level of information is too high regarding the actual information available in iSERV. A new approach was then proposed based on the limited information available.

4.1.4 Heat transfer by ventilation

The total heat transfer by ventilation, Q_{ve}, takes into account the mechanical ventilation and the infiltration. Q_{ve} is calculated for each month and for each zone by the equations:

- ➔ For heating : $Q_{h_{ve}} = \left(f_{ve} * H_{h_{ve}} + H_{inf}\right) * \left(T_{i_{set_h}} - T_{e_m}\right) * \Delta t$
- ➔ For cooling : $Q_{c_{ve}} = \left(f_{ve} * H_{c_{ve}} + H_{inf}\right) * \left(T_{i_{set_c}} - T_{e_m}\right) * \Delta t$

The mechanical heat transfer coefficient is based on the ventilation airflow rate and on a time fraction of operation while the infiltration transfer coefficient is evaluated as Air-Change-per-Hour (ACH).

4.1.5 Internal heat gains

The internal heat gains include the metabolic heat from occupants and the dissipated heat from lighting and appliances. Standard input data were introduced for different type of activity based on standardized assumptions for non-residential buildings (Stocki et al., 2007) and ISO 13790 – Annex G.

$$Q_{int} = f_{appl} * Q_{appl} + f_{occ} * Q_{occ} + f_{light} * Q_{light} \quad \textbf{(4.17)}$$

4.1.6 Solar heat gains

The heat flow by solar gains is given by the following equation:

$$Q_{sol} = \left(F_{sh_N} * A_{sol_N} * I_{N_m} + F_{sh_E} * A_{sol_E} * I_{E_m} + F_{sh_S} * A_{sol_S} * I_{S_m} + F_{sh_W} * A_{sol_W} * I_{W_m}\right) * \frac{\Delta t}{1000} \quad \textbf{(4.18)}$$

This equation takes into account a shading factor by orientation.

4.1.7 Dynamic parameters

In the ISO13790 monthly method, the dynamic effects are taken into account by introducing the gain utilization factor for heating and the loss utilization factor for cooling.

4.1.7.1 Gain utilization factor for heating

To evaluate the energy need for heating, a usable fraction of heat losses was introduced based on the dimensionless gain utilization factor for heating $\eta_{H,gn}$.

Figure 12 illustrates gain utilization factor for various time constants.

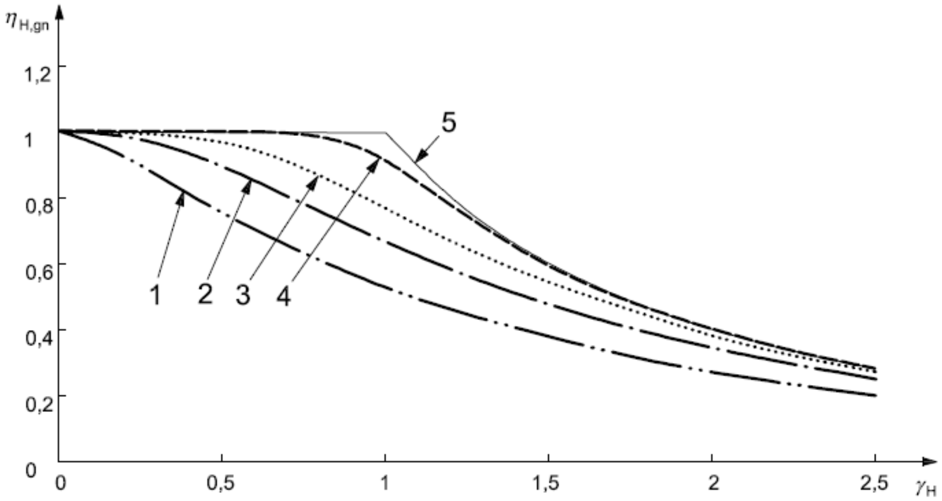

Figure 12 – Illustration of gain utilization factor for heating mode, for 8 h (1), 1 d (2), 2 d (3), 7 d (4) and infinite (5) time constants, valid for monthly calculation method.

It is a function of the heat-balance ratio γ_H and a numerical parameter, a_H, that depends on the building inertia.

$$If\ \gamma_H \neq 1\ and\ \gamma_H > 0 \quad \Rightarrow \quad \eta_{H,gh} = \frac{1 - \gamma_H^{a_H}}{1 - \gamma_H^{a_H+1}}$$

$$If\ \gamma_H = 1 \quad ⇨ \quad \eta_{H,gh} = \frac{a_H}{a_H + 1}$$

$$If\ \gamma_H < 0 \quad ⇨ \quad \eta_{H,gh} = 1$$

4.1.7.2 Loss utilization factor for cooling

To evaluate the energy need for cooling, a usable fraction of internal gains was introduced, also with dependence on the building thermal inertia and of the heat-balance ratio.

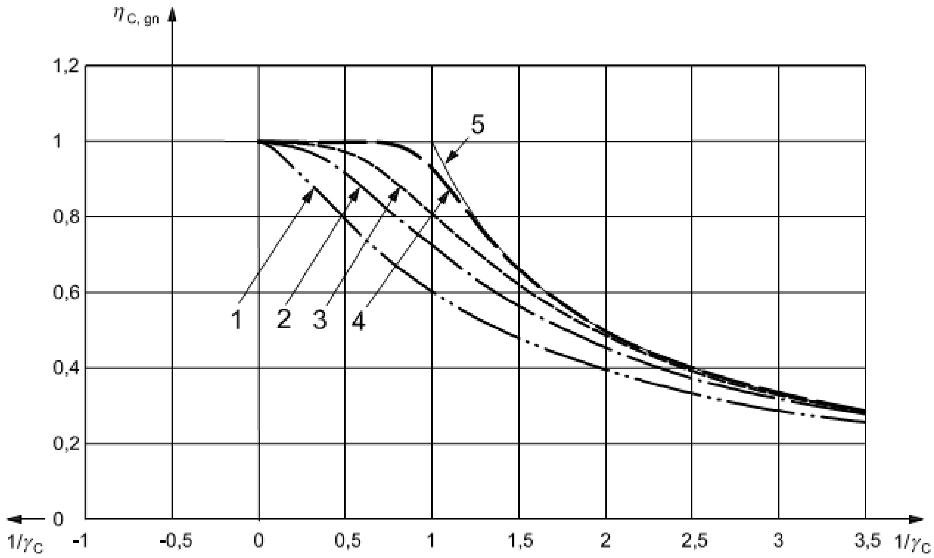

Figure 13 – Illustration of loss utilization factor for 8 h (1), 1 d (2), 2 d (3), 7 d (4) and infinite (5) time constants, valid for monthly calculation method.

$$If\ \gamma_C \neq 1\ and\ \gamma_C > 0 \quad ⇨ \quad \eta_{C,ls} = \frac{1 - \gamma_C^{-a_C}}{1 - \gamma_C^{-(a_C+1)}}$$

$$If\ \gamma_C = 1 \quad ⇨ \quad \eta_{C,ls} = \frac{a_C}{a_C + 1}$$

$$If\ \gamma_C < 0 \quad ⇨ \quad \eta_{C,ls} = 1$$

4.1.8 Length of heating and cooling seasons

Furthermore ISO 13790 method also proposes a simple method to determine the number of hours of operation for certain season-length-dependent provisions (e.g. pumps, fans, central pre-heating). This can be determined as follows. The fraction of the month that is part of the heating season is calculated by using the following equation.

$$f_h = \frac{Q_{h_{nd}}}{Q_{h_{nd}} + Q_{c_{nd}} + Q_{ve_{preheat}} + Q_{ve_{precool}}} \quad \textbf{(4.19)}$$

The fraction of the month that is part of the cooling season is calculated by using the following equation:

$$f_c = \frac{Q_{c_{nd}}}{Q_{h_{nd}} + Q_{c_{nd}}} \quad (4.20)$$

4.2 ISO 13790 – Model verification

In order to verify the accuracy of the model and to check that no errors were made during its construction, the norm ISO 13790 propose the evaluation of a test case.

The internal dimensions of the room are: length =3.6 m; depth =5.5 m; height =2.8 m. The external wall including window glazing is facing west and meteorological data for Paris is used.

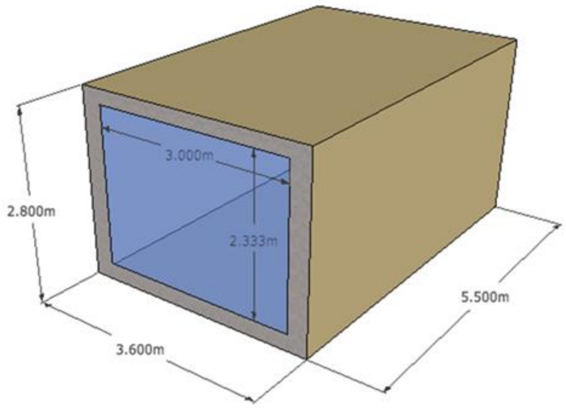

Figure 14 - Test cell proposed by ISO 13790

A detailed description about the inputs and parameters used in this verification exercise are done in the *Annex J: Worked example; simple hourly and monthly methods* of the ISO13790 standard.

They are related to: Building dimensions, transmission characteristics, ventilation characteristics, solar heat gain characteristics, internal heat gains, building time constant, use of the building and climate data.

The results obtained for the model verification performed for the model built to evaluate ECOs is shown in Figure 15.

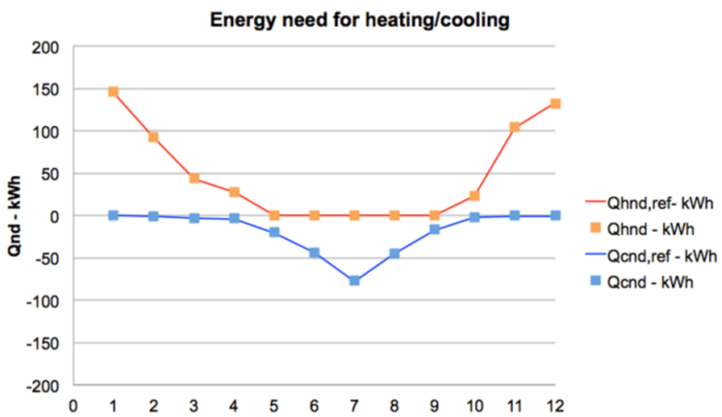

Figure 15 – Results obtained in model verification of ECO tool

A perfect agreement between model and expected results can be seen. Although this validation doesn't allow certifying all the assumptions performed for the ECO tool presented in the current report, this ensures the accuracy of the core-model according to the standard.