X SICEL 2021

Transición energética en la 4ta revolución industrial

Universidad Tecnológica de Pereira

UNIVERSIDAD NACIONAL DE COLOMBIA

XSICEL 2021

Transición energética en la 4ta revolución industrial

Constructing a Composite Indicator to Analyze Building Energy Performance

Marlon Millan Martinez, Ph.D. German A. Osma Pinto, Ph.D. Julian E. Jaramillo Ibarra

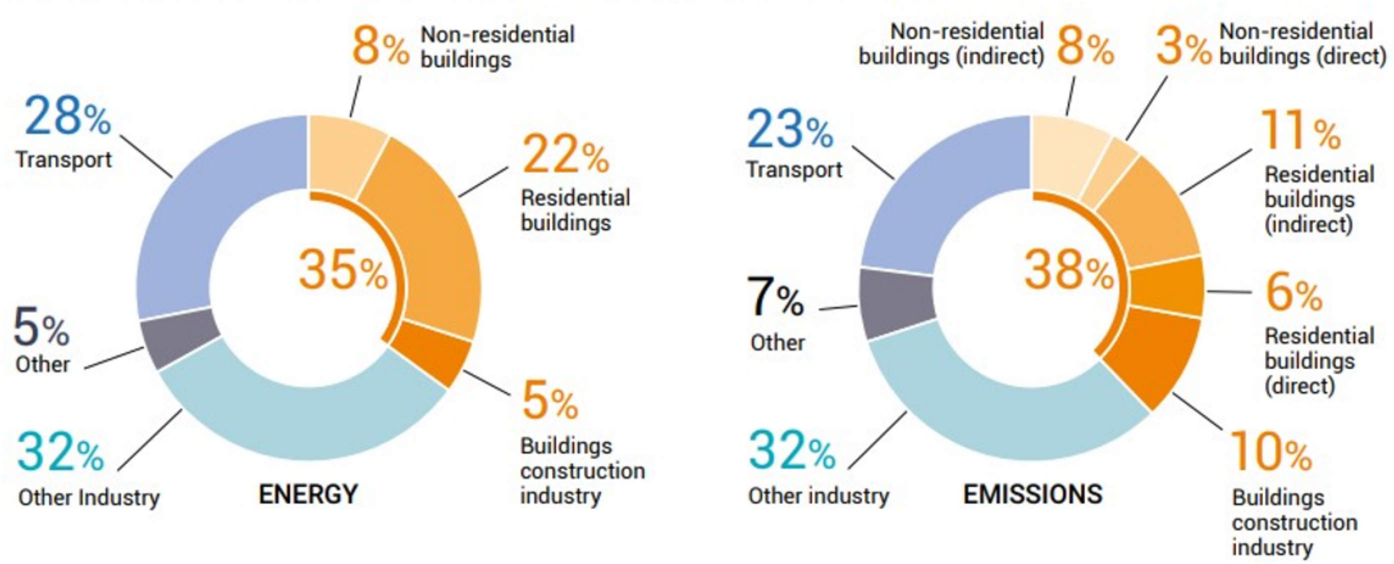
Universidad Industrial de Santander
Bucaramanga, Santander

Universidad Industrial de Santander

Contents

I. Introduction

➢ **Buildings** consume about **40%** of **end-use energy** and produce **30%** of **CO_2**.



Source: 2020 Global Status Report for Buildings and Construction: Towards a zero-emissions, efficient and resilient buildings and construction sector.

I. Introduction

- **Buildings** consume about **40%** of **end-use energy** and produce **30%** of **CO_2**.

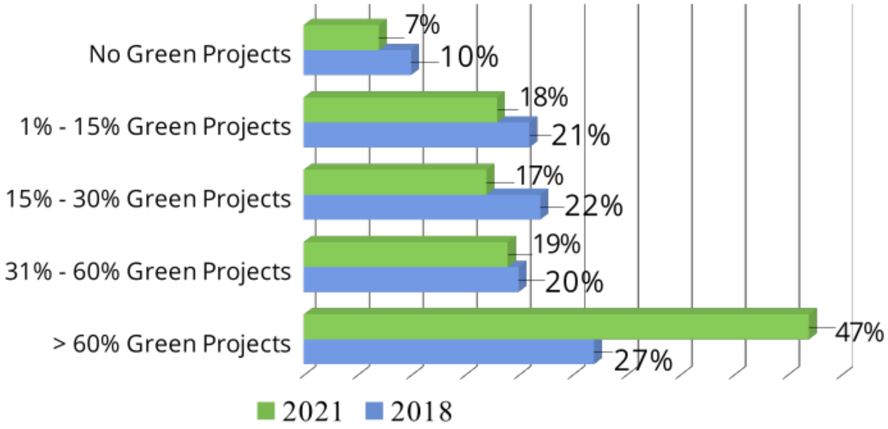
- Buildings energy demand depends on architectural design, external an internal conditions.

I. Introduction

- **Buildings** consume about **40%** of **end-use energy** and produce **30%** of **CO_2**.

- Buildings energy demand depends on architectural design, external an internal conditions.

- A **growing interest** in promoting the integration of **sustainability practices** in buildings (Green Buildings).



Level of Green Building Activity

Source: World Green Buildings Trends 2018. Smartmarket Report.

I. Introduction

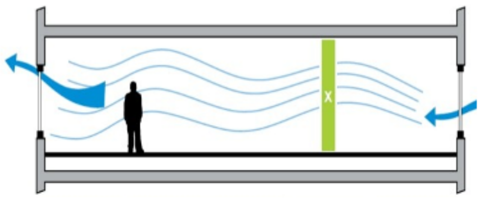
- **Buildings** consume about **40%** of **end-use energy** and produce **30%** of **CO_2**.

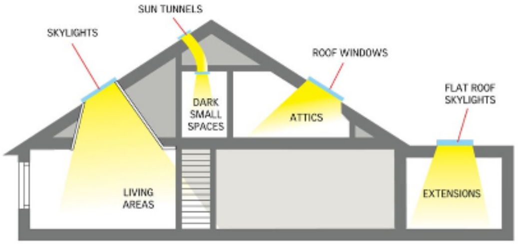
- Buildings energy demand depends on architectural design, external an internal conditions.

- A **growing interest** in promoting the integration of **sustainability practices** in buildings (Green Buildings).

- **Green Buildings** incorporate **energy strategies** (passives and/or actives) to **reduce energy consumption.**

Automation systems and efficient equipment

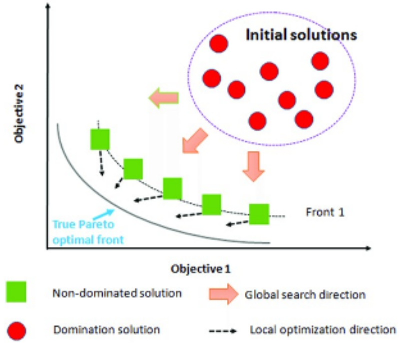




Natural ventilation and lighting

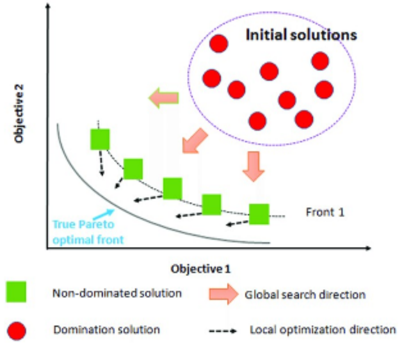
I. Introduction

➢ **Parametric analysis** and **multi-objective optimization** approach are used to **select the energy strategies** for buildings.



I. Introduction

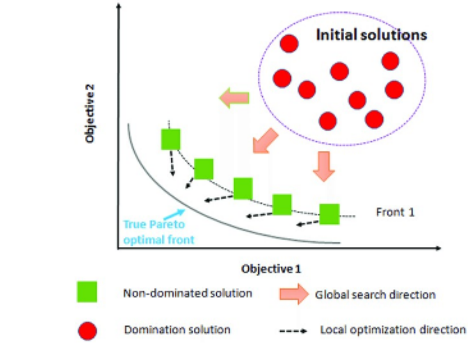
- **Parametric analysis** and **multi-objective optimization** approach are used to **select the energy strategies** for buildings.



- Many studies analyzing **buildings energy performance (BEP)** with energy modeling tools.

I. Introduction

- **Parametric analysis** and **multi-objective optimization** approach are used to **select the energy strategies** for buildings.



- Many studies analyzing **buildings energy performance (BEP)** with energy modeling tools.

- Building energy analysis estimate **individual indices** (energy lifecycle, energy-savings, thermal comfort).

- Some **buildings metrics** also estimate in this studies (energy intensities, energy cost, sensible heat gain, predicted percentage of dissatisfied (PPD), etc).

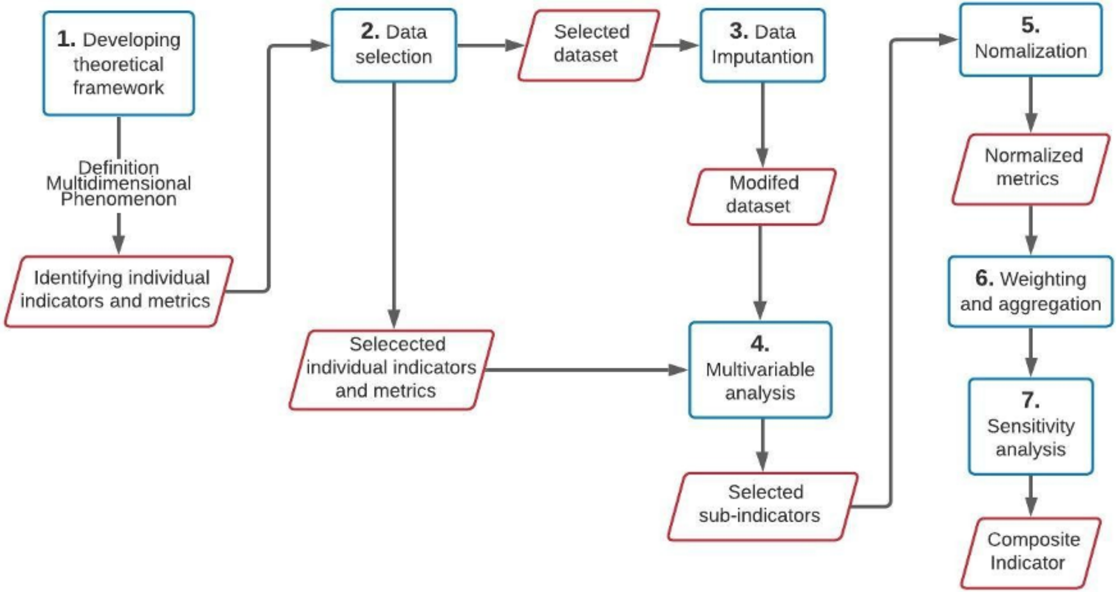
I. Introduction

- **Buildings** are **complex systems** and its energy analysis could be consider a **multidimensional phenomenon**.

I. Introduction

- **Buildings** are **complex systems** and its energy analysis could be consider a **multidimensional phenomenon.**

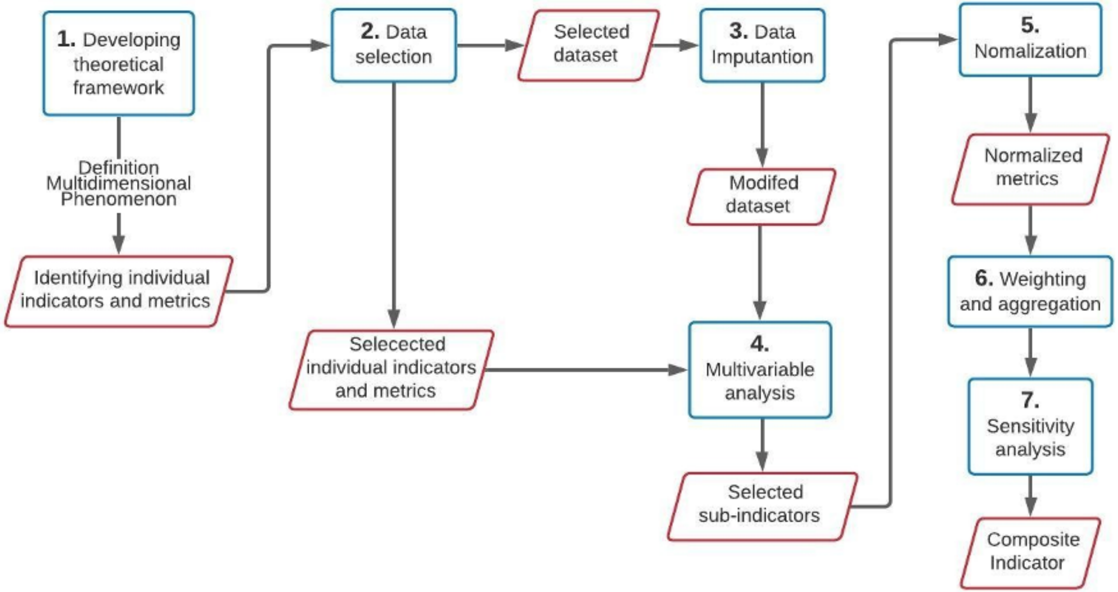
- **Composite Indicators** (CI's) are a useful tool used to **describe multidimensional phenomena.**



I. Introduction

- **Buildings** are **complex systems** and its energy analysis could be consider a **multidimensional phenomenon**.

- **Composite Indicators** (CI's) are a useful tool used to **describe multidimensional phenomena**.



- Some composite and individual indicator (energy approach).

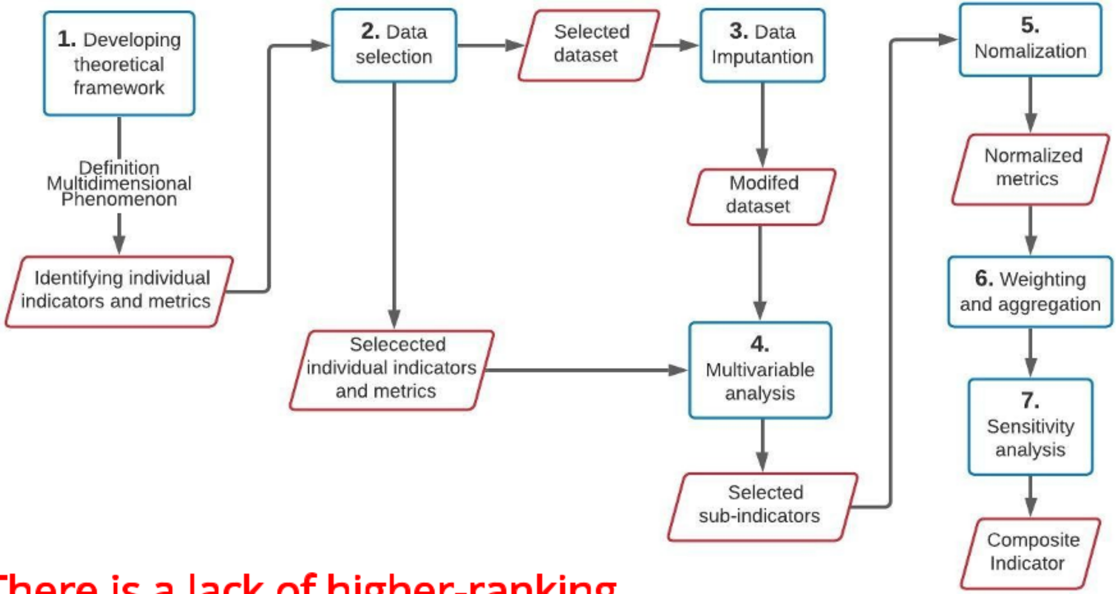
  - **Energy security**
  - **Energy sustainability**
  - **Energy resilience**
  - Energy use
  - Energy loss
  - Thermal load

I. Introduction

- **Buildings** are **complex systems** and its energy analysis could be consider a **multidimensional phenomenon.**

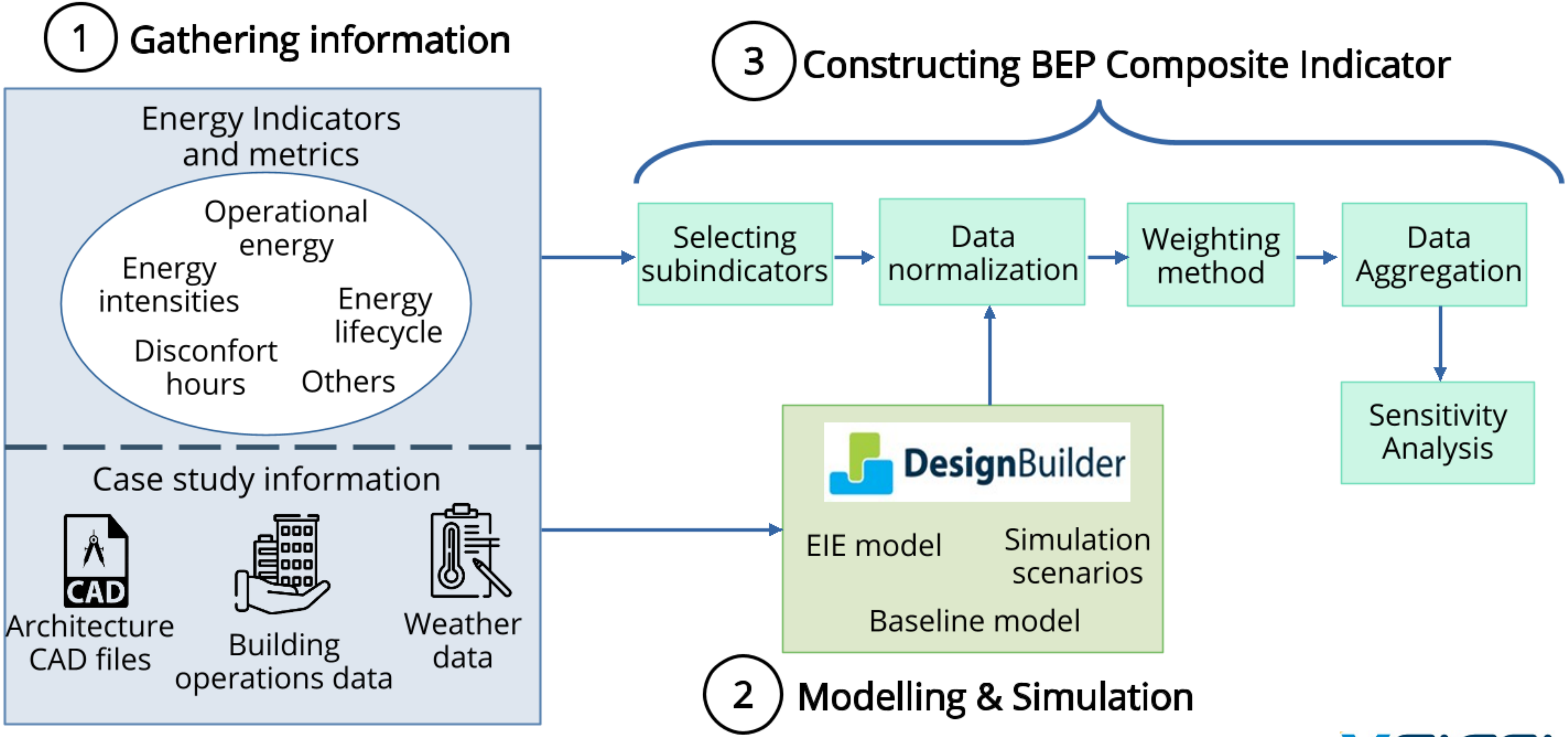
- **Composite Indicators** (CI's) are a useful tool used to **describe multidimensional phenomena.**

- Some composite and individual indicator (energy approach).
  - **Energy security**
  - **Energy sustainability**
  - **Energy resilience**
  - Energy use
  - Energy loss
  - Thermal load



There is a lack of higher-ranking indicators to evaluate the BEP.

II. Proposed methodology



II. Proposed methodology

3 Constructing BEP Composite Indicator

Sub-indicators
- Energy Efficiency (EE)
- Thermal Comfort (CO)

II. Proposed methodology

3 Constructing BEP Composite Indicator

Sub-indicators
- Energy Efficiency (EE)
  - Total annual energy Consumption (M_{EE1})
  - Lighting annual energy Consumption (M_{EE2})
  - HVAC annual energy Consumption (M_{EE3})
- Thermal Comfort (CO)
  - Discomfort hours (M_{CO1})
  - Predicted percentage of dissatisfied (M_{CO2})

II. Proposed methodology

3 Constructing BEP Composite Indicator

- Sub-indicators
  - Energy Efficiency (EE)
    - Total annual energy Consumption (M_{EE1})
    - Lighting annual energy Consumption (M_{EE2})
    - HVAC annual energy Consumption (M_{EE3})
  - Thermal Comfort (CO)
    - Discomfort hours (M_{CO1})
    - Predicted percentage of dissatisfied (M_{CO2})

$$BEP = \varphi\left(\overline{EE}\right) + \alpha\left(\overline{CO}\right), \quad 0 \leq BEP \leq 1 \qquad (1)$$

$$\overline{EE} = \frac{1}{n}\sum_{i}^{n}\overline{M}_{EE,i}\ , \ \overline{CO} = \frac{1}{n}\sum_{i}^{n}\overline{M}_{CO,i} \qquad (2)$$

$$0 \leq \varphi, \alpha \leq 1; \quad \varphi + \alpha = 1 \qquad (3)$$

II. Proposed methodology

- **Sensitivity Analysis**

Data normalization:

- Difference to value reference (DVR) → $I_{qc} = \frac{x_{qc} - x_{qr}}{x_{qr}}$
- Standardization (Z-score) → $I_{qc} = \frac{x_{qc} - x_{qc=c}}{\sigma_{qc=c}}$

II. Proposed methodology

- **Sensitivity Analysis**

Data normalization

- Difference to value reference (DVR) → $I_{qc} = \frac{x_{qc} - x_{qr}}{x_{qr}}$
- Standardization (Z-score) → $I_{qc} = \frac{x_{qc} - x_{qc=c}}{\sigma_{qc=c}}$

Data Aggregation

- Weighted linear → $CI = \sum_{i=1}^{N} w_i I_i$
- Geometric weighted → $CI = \prod_{i=1}^{N} (I_i)^{w_i}$

II. Proposed methodology

- **Sensitivity Analysis**

Data normalization

- Difference to value reference (DVR) → $I_{qc} = \frac{x_{qc} - x_{qr}}{x_{qr}}$
- Standardization (Z-score) → $I_{qc} = \frac{x_{qc} - x_{qc=c}}{\sigma_{qc=c}}$

Data Aggregation

- Weighted linear → $CI = \sum_{i=1}^{N} w_i I_i$
- Geometric weighted → $CI = \prod_{i=1}^{N} (I_i)^{w_i}$

Weighting

- Equal weights → φ = α = 0.5
- Weight Sets → φ = 0.65; α = 0.35 / φ = 0.35; α = 0.65

III. Case study and simulation scenarios

Electrical Engineering Building (EEB)

Table 1. Building's characteristics

Building features	Description
Location	7.13° North, 73.13° West
Altitude	960 masl
Area approx.	2 700 m^2)
Occupation approx.	1 400 person
Building orientation (main façade)	South-North
Floors numbers	5 floors and a basement
Building area use	Classroom, study room, administrative and teacher offices

III. Case study and simulation scenarios

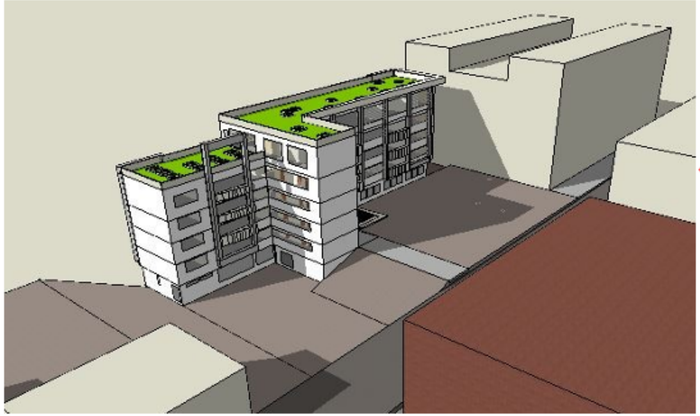
Electrical Engineering Building (EEB)

Table 1. Building’s characteristics

Building features	Description
Location	7.13° North, 73.13° West
Altitude	960 masl
Area approx.	2 700 m^2)
Occupation approx.	1 400 person
Building orientation (main façade)	South-North
Floors numbers	5 floors and a basement
Building area use	Classroom, study room, administrative and teacher offices

- 23 Solar tubes
- Green roof: 580 m^2
- PV System: 11.55 kW installed
- Shading elements (louvres)

III. Case study and simulation scenarios

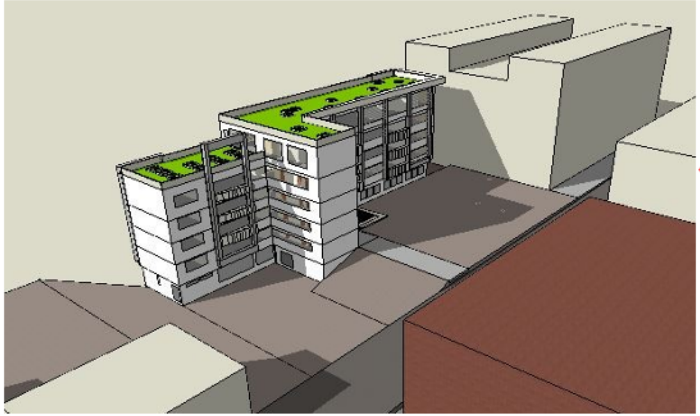


EEB's energy model.

Table 2. EEB's Energy model construction elements

Element	Material	Thickness (m)	U-Value
Exterior and interior walls	Drywall Mortar Coated Brick	0.15 0.15	2.061 1.470
Floors	Lightened concrete	0.40	1.603
Roofs	Lightened concrete Green roof	0.40 0.71	1.603 0.358
Windows	Clear glass (SHGC = 0.85)	0.04	5.871
Doors	Oak Metal lattice	0.01 0.035	2.823 5.858

III. Case study and simulation scenarios

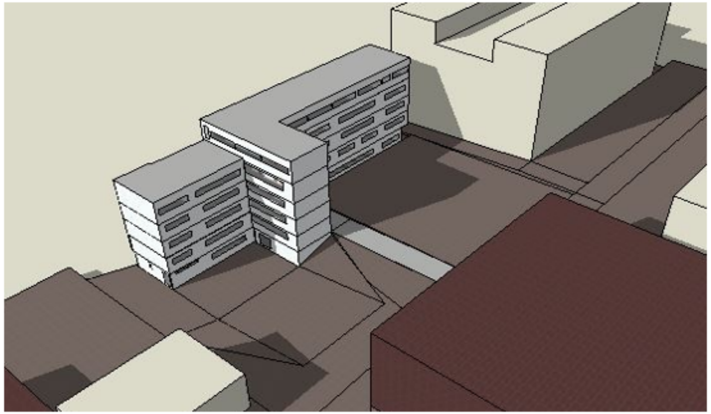


EEB's energy model.

DesignBuilder

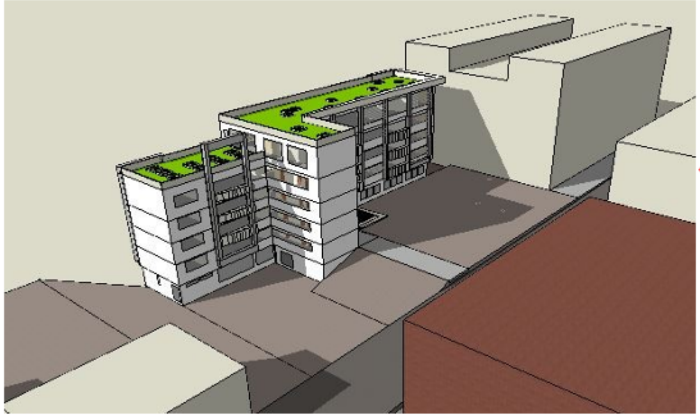
ASHRAE

Standar 90.1
Apendix G



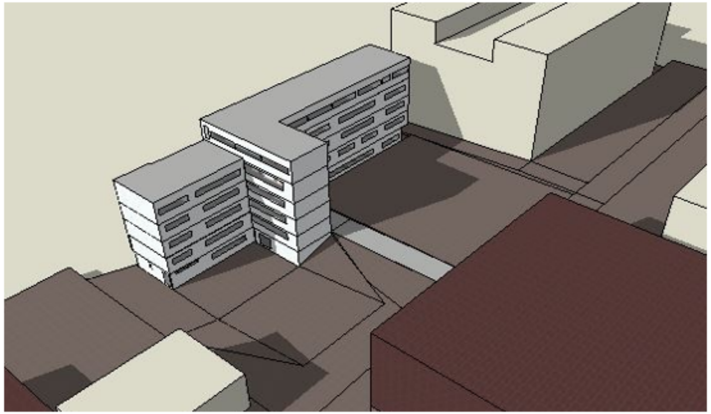
EEB's base line energy model

III. Case study and simulation scenarios



EEB's energy model.

DesignBuilder



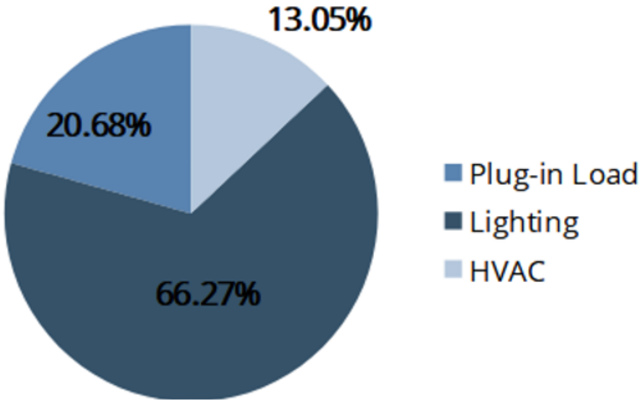
EEB's base line energy model

Table 3. Simulation Scenarios

Scenario	Description	Modified parameter	Parameter value
ES1	Current conditions model	-	-
ES2	Baseline model	-	-
ES3	Baseline model modifying % Wall-Window	% Wall-Window	40%
ES4	Baseline model modifying % Wall-Window	% Wall-Window	50%
ES5	Baseline model + Solar tube	Basemodel + ES1 solar tubes	-
ES6	Baseline model + green roof	ES1 green roof	-
ES7	Baseline model + Louvre	Blade depth	0.5 m
ES8	Baseline model + Louvre	Blade depth	1.5 m

IV. Results

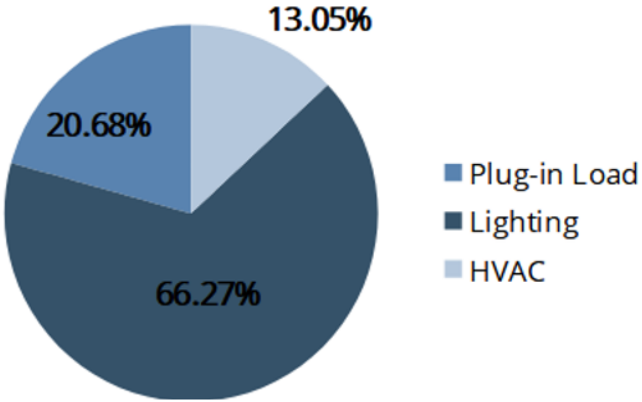
Dis-aggregated energy consumption



- The most energy consumption is due to the lighting system.

IV. Results

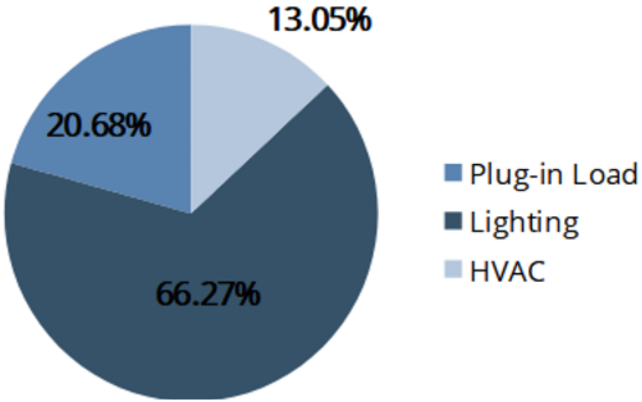
Dis-aggregated energy consumption



- The most energy consumption is due to the lighting system.
- HVAC system has an energy consumption relatively low.

IV. Results

Dis-aggregated energy consumption



- The most energy consumption is due to the lighting system.
- HVAC system has an energy consumption relatively low.

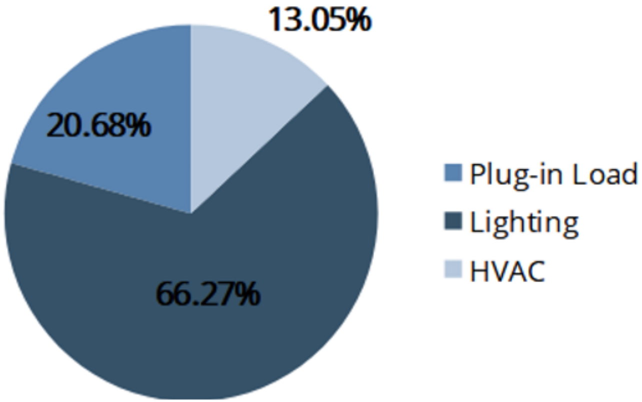
Table 4. Non-normalized metrics result

Scenario	M_{EE1} (kWh)	M_{EE2} (kWh)	M_{EE3} (kWh)	M_{CO1} (hours)	M_{CO2} (%)
ES1	160 866.2	106 612.4	20 986.5	2 389.3	24.4
ES2	232 004.5	114 896.6	83 795.3	2 373.4	29.7
ES3	227 583.0	110 574.8	83 695.7	2 373.1	30.4
ES4	227 086.2	109 565.6	84 208.0	2 372,8	30.8
ES5	231 934.4	114 896.3	83 725.5	2 373.5	29.7
ES6	232 271.5	114 816.9	84 142.0	2 373.0	30.4
ES7	232 369.3	116 480.1	82 576.7	2 376.8	30.0
ES8	235 849.5	120 460.5	82 076.4	2 380.1	28.7

Modifying window area reduces lighting energy consumption (4% approx) and increases HVAC consumption.

IV. Results

Dis-aggregated energy consumption



- The most energy consumption is due to the lighting system.
- HVAC system has an energy consumption relatively low.

Table 4. Non-normalized metrics result

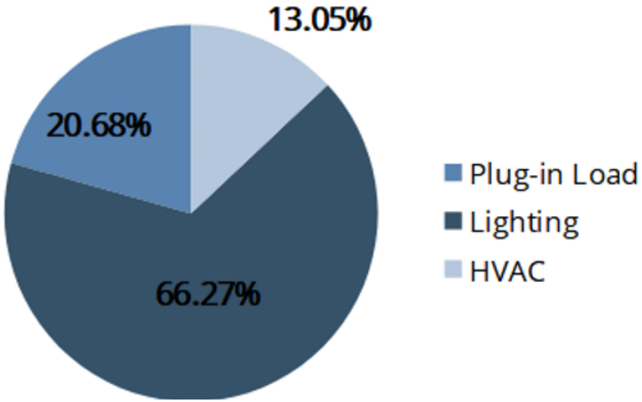
Scenario	M_{EE1} (kWh)	M_{EE2} (kWh)	M_{EE3} (kWh)	M_{CO1} (hours)	M_{CO2} (%)
ES1	160 866.2	106 612.4	20 986.5	2 389.3	24.4
ES2	232 004.5	114 896.6	83 795.3	2 373.4	29.7
ES3	227 583.0	110 574.8	83 695.7	2 373.1	30.4
ES4	227 086.2	109 565.6	84 208.0	2 372,8	30.8
ES5	231 934.4	114 896.3	83 725.5	2 373.5	29.7
ES6	232 271.5	114 816.9	84 142.0	2 373.0	30.4
ES7	232 369.3	116 480.1	82 576.7	2 376.8	30.0
ES8	235 849.5	120 460.5	82 076.4	2 380.1	28.7

Modifying window area reduces lighting energy consumption (4% approx) and increases HVAC consumption.

External shading elements increase energy consumption for lighting (4% approx) and reduce consumption for HVAC by 2%.

IV. Results

Dis-aggregated energy consumption



- The most energy consumption is due to the lighting system.
- HVAC system has an energy consumption relatively low.

Table 4. Non-normalized metrics result

Scenario	M_{EE1} (kWh)	M_{EE2} (kWh)	M_{EE3} (kWh)	M_{CO1} (hours)	M_{CO2} (%)
ES1	160 866.2	106 612.4	20 986.5	2 389.3	24.4
ES2	232 004.5	114 896.6	83 795.3	2 373.4	29.7
ES3	227 583.0	110 574.8	83 695.7	2 373.1	30.4
ES4	227 086.2	109 565.6	84 208.0	2 372,8	30.8
ES5	231 934.4	114 896.3	83 725.5	2 373.5	29.7
ES6	232 271.5	114 816.9	84 142.0	2 373.0	30.4
ES7	232 369.3	116 480.1	82 576.7	2 376.8	30.0
ES8	235 849.5	120 460.5	82 076.4	2 380.1	28.7

Modifying window area reduces lighting energy consumption (4% approx) and increases HVAC consumption.

External shading elements increase energy consumption for lighting (4% approx) and reduce consumption for HVAC by 2%.

The integration of energy strategies in the EEB reduces energy consumption by 30.6%.

IV. Results and Discussion

Table 5. BEP results with DVR normalization data and weighted linear aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.159	0.171	0.147
ES3	0.006	0.007	0.005
ES4	0.008	0.008	0.007
ES5	0.002	0.001	0.002
ES6	0.001	0.001	0.001
ES7	0.011	0.010	0.011
ES8	0.030	0.024	0.035

Table 6. BEP results with DVR normalization data and geometric aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.154	0.166	0.143
ES3	0.006	0.006	0.005
ES4	0.007	0.008	0.006
ES5	0.001	0.001	0.002
ES6	0	0	0
ES7	0.01	0.009	0.011
ES8	0.022	0.017	0.028

IV. Results and Discussion

Table 5. BEP results with DVR normalization data and weighted linear aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.159	0.171	0.147
ES3	0.006	0.007	0.005
ES4	0.008	0.008	0.007
ES5	0.002	0.001	0.002
ES6	0.001	0.001	0.001
ES7	0.011	0.010	0.011
ES8	0.030	0.024	0.035

Table 6. BEP results with DVR normalization data and geometric aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.154	0.166	0.143
ES3	0.006	0.006	0.005
ES4	0.007	0.008	0.006
ES5	0.001	0.001	0.002
ES6	0	0	0
ES7	0.01	0.009	0.011
ES8	0.022	0.017	0.028

Weights consistently influences the BEP indicator calculation (differences relatively small 0 and 0.012).

IV. Results and Discussion

Table 5. BEP results with DVR normalization data and weighted linear aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.159	0.171	0.147
ES3	0.006	0.007	0.005
ES4	0.008	0.008	0.007
ES5	0.002	0.001	0.002
ES6	0.001	0.001	0.001
ES7	0.011	0.010	0.011
ES8	0.030	0.024	0.035

Table 6. BEP results with DVR normalization data and geometric aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.154	0.166	0.143
ES3	0.006	0.006	0.005
ES4	0.007	0.008	0.006
ES5	0.001	0.001	0.002
ES6	0	0	0
ES7	0.01	0.009	0.011
ES8	0.022	0.017	0.028

Weights consistently influences the BEP indicator calculation (differences relatively small 0 and 0.012).

Weighted linear aggregation method estimated slightly higher values are estimated compared to the geometric aggregation.

IV. Results and Discussion

Table 5. BEP results with DVR normalization data and weighted linear aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.159	0.171	0.147
ES3	0.006	0.007	0.005
ES4	0.008	0.008	0.007
ES5	0.002	0.001	0.002
ES6	0.001	0.001	0.001
ES7	0.011	0.010	0.011
ES8	0.030	0.024	0.035

Weights consistently influences the BEP indicator calculation (differences relatively small 0 and 0.012).

Weighted linear aggregation method estimated slightly higher values are estimated compared to the geometric aggregation.

Table 6. BEP results with DVR normalization data and geometric aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.154	0.166	0.143
ES3	0.006	0.006	0.005
ES4	0.007	0.008	0.006
ES5	0.001	0.001	0.002
ES6	0	0	0
ES7	0.01	0.009	0.011
ES8	0.022	0.017	0.028

The EEB model (ES1 scenario) presents the most significant variation (7.5% approx).

IV. Results and Discussion

Table 7. BEP results with Z-score normalization data and weighted linear aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.259	0.261	0.257
ES3	0.011	0.012	0.009
ES4	0.013	0.015	0.01
ES5	0.001	0.001	0.001
ES6	0.002	0.001	0.002
ES7	0.013	0.011	0.015
ES8	0.024	0.019	0.029

Table 8. BEP results with Z-score normalization data and geometric aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.259	0.261	0.257
ES3	0.008	0.01	0.007
ES4	0.010	0.012	0.008
ES5	0.000	0.000	0.000
ES6	0.001	0.001	0.002
ES7	0.011	0.009	0.013
ES8	0.017	0.013	0.022

IV. Results and Discussion

Table 7. BEP results with Z-score normalization data and weighted linear aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.259	0.261	0.257
ES3	0.011	0.012	0.009
ES4	0.013	0.015	0.01
ES5	0.001	0.001	0.001
ES6	0.002	0.001	0.002
ES7	0.013	0.011	0.015
ES8	0.024	0.019	0.029

Table 8. BEP results with Z-score normalization data and geometric aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.259	0.261	0.257
ES3	0.008	0.01	0.007
ES4	0.010	0.012	0.008
ES5	0.000	0.000	0.000
ES6	0.001	0.001	0.002
ES7	0.011	0.009	0.013
ES8	0.017	0.013	0.022

The BEP indicator values are consistent and do not present considerable differences.

IV. Results and Discussion

Table 7. BEP results with Z-score normalization data and weighted linear aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.259	0.261	0.257
ES3	0.011	0.012	0.009
ES4	0.013	0.015	0.01
ES5	0.001	0.001	0.001
ES6	0.002	0.001	0.002
ES7	0.013	0.011	0.015
ES8	0.024	0.019	0.029

Table 8. BEP results with Z-score normalization data and geometric aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.259	0.261	0.257
ES3	0.008	0.01	0.007
ES4	0.010	0.012	0.008
ES5	0.000	0.000	0.000
ES6	0.001	0.001	0.002
ES7	0.011	0.009	0.013
ES8	0.017	0.013	0.022

The BEP indicator values are consistent and do not present considerable differences.

With geometric aggregation method, one sub-indicator could cancel out the impact of the others on CI.

IV. Results and Discussion

Table 7. BEP results with Z-score normalization data and weighted linear aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.259	0.261	0.257
ES3	0.011	0.012	0.009
ES4	0.013	0.015	0.01
ES5	0.001	0.001	0.001
ES6	0.002	0.001	0.002
ES7	0.013	0.011	0.015
ES8	0.024	0.019	0.029

Table 8. BEP results with Z-score normalization data and geometric aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.259	0.261	0.257
ES3	0.008	0.01	0.007
ES4	0.010	0.012	0.008
ES5	0.000	0.000	0.000
ES6	0.001	0.001	0.002
ES7	0.011	0.009	0.013
ES8	0.017	0.013	0.022

The BEP indicator values are consistent and do not present considerable differences.

With geometric aggregation method, one sub-indicator could cancel out the impact of the others on CI.

DRV method show slight variations (between 0 and 0.005), but the z-score method values are equal.

IV. Results and Discussion

Table 7. BEP results with Z-score normalization data and weighted linear aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.259	0.261	0.257
ES3	0.011	0.012	0.009
ES4	0.013	0.015	0.01
ES5	0.001	0.001	0.001
ES6	0.002	0.001	0.002
ES7	0.013	0.011	0.015
ES8	0.024	0.019	0.029

The BEP indicator values are consistent and do not present considerable differences.

With geometric aggregation method, one sub-indicator could cancel out the impact of the others on CI.

Table 8. BEP results with Z-score normalization data and geometric aggregation

Scenario	BEP		
	φ =0.5; α=0.5	φ=0.65; α=0.35	φ=0.35; α=0.65
ES1	0.259	0.261	0.257
ES3	0.008	0.01	0.007
ES4	0.010	0.012	0.008
ES5	0.000	0.000	0.000
ES6	0.001	0.001	0.002
ES7	0.011	0.009	0.013
ES8	0.017	0.013	0.022

DRV method show slight variations (between 0 and 0.005), but the z-score method values are equal.

Green roofs and Solar tubes (ES5 and ES6) have a negligible impact on BEP indicator.

IV. Results and Discussion

- EE sub-indicator has a greater incidence in the BEP than the CO sub-indicator.

IV. Results and Discussion

- EE sub-indicator has a greater incidence in the BEP than the CO sub-indicator.
- Energy strategies improves the EEB's BEP by approximately 16% (DRV method and weighted linear aggregation).

IV. Results and Discussion

- EE sub-indicator has a greater incidence in the BEP than the CO sub-indicator.
- Energy strategies improves the EEB's BEP by approximately 16% (DRV method and weighted linear aggregation).
- If BEP had been evaluated only with individual indicators higher values would be obtained (30% approx).

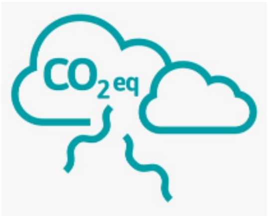
IV. Results and Discussion

- EE sub-indicator has a greater incidence in the BEP than the CO sub-indicator.

- Energy strategies improves the EEB's BEP by approximately 16% (DRV method and weighted linear aggregation).

- If BEP had been evaluated only with individual indicators higher values would be obtained (30% approx)

- Disruptive scenarios, greenhouse gas (GHG) emissions, visual comfort and building adaptability don't evaluated.



V. Conclusions

- The BEP indicator was **evaluated and validated** through a **sensitivity analysis** that took into account different aggregation methods, data normalization and weight values for the sub-indicators. The integration of **energy strategies** in the EEB **improves the BEP** by approximately **16%.**

V. Conclusions

- The BEP indicator was **evaluated and validated** through a **sensitivity analysis** that took into account different aggregation methods, data normalization and weight values for the sub-indicators. The integration of **energy strategies** in the EEB **improves the BEP** by approximately **16%.**
- The approach presented in this work **allows having a global perspective** of the **building operation** in specific conditions. The **relative simplicity** to evaluate the BEP indicator **makes it easy to apply it to other buildings types** (e.g., residential, commercial, or industrial) and thus contribute to the **possible buildings energy characterization**.

V. Conclusions

- The BEP indicator was **evaluated and validated** through a **sensitivity analysis** that took into account different aggregation methods, data normalization and weight values for the sub-indicators. The integration of **energy strategies** in the EEB **improves the BEP** by approximately **16%.**
- The approach presented in this work **allows having a global perspective** of the **building operation** in specific conditions. The **relative simplicity** to evaluate the BEP indicator **makes it easy to apply it to other buildings types** (e.g., residential, commercial, or industrial) and thus contribute to the **possible buildings energy characterization**.
- It is expected that the **BEP indicator will become a helpful tool** for **decision-making** in the building's **design or refurbish processes** that favor the integration of sustainability criteria.

V. Conclusions

- The BEP indicator was **evaluated and validated** through a **sensitivity analysis** that took into account different aggregation methods, data normalization and weight values for the sub-indicators. The integration of **energy strategies** in the EEB **improves the BEP** by approximately **16%.**
- The approach presented in this work **allows having a global perspective** of the **building operation** in specific conditions. The **relative simplicity** to evaluate the BEP indicator **makes it easy to apply it to other buildings types** (e.g., residential, commercial, or industrial) and thus contribute to the **possible buildings energy characterization**.
- It is expected that the **BEP indicator will become a helpful tool** for **decision-making** in the building's **design or refurbish processes** that favor the integration of sustainability criteria.
- For future works, we consider **expanding the BEP indicator** to include **buildings adaptability, greenhouse gas (GHG) emissions and economics**. Likewise, it is desirable to validate the BEP indicator with experimental data.

VI. Questions