

COB-2023-1166

APPLICATION OF THE INMETRO NORMATIVE INSTRUCTION FOR CLASSIFYING THE ENERGY EFFICIENCY OF A FEDERAL PUBLIC BUILDING

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Abstract. Brazil ranks seventh among countries that consume electricity and, in order to avoid limiting consumption measures, it has been adopting several actions, the main one being the increase in the electricity generation park, through the construction of new hydroelectric and thermal plants. However, several economic and environmental restrictions hinder the advancement of these practices. An effective measure, widely used in developed and developing countries, is the adoption of mandatory regulations or voluntary energy efficiency standards, which aim to control the increase in electricity consumption and promote the energy efficiency of non-residential buildings. In 2018, the National Institute of Metrology, Quality and Technology (Inmetro) came into effect the Inmetro Normative Instruction for the Energy Efficiency Classification of Commercial, Services and Public Buildings (INI-C). This article aims to evaluate the applicability of this new methodology in existing buildings at a federal public building located in the city of Rio de Janeiro. The final classification was presented with a view to possible future energy certification.

Keywords: energy efficiency, building energy codes, electricity consumption, INI-C

1. INTRODUCTION

Consolidated data from the Electric Energy Statistical Yearbook (EPE, 2018) have demonstrated the growth in electricity consumption in Brazil, even after the forced reduction caused by energy rationing in 2001. This trend is closely correlated with the expansion of gross domestic product (GDP), reflecting the economic upturn in Brazil that occurred before the 2016 economic crisis.

Buildings account for 30% of global energy consumption and over 55% of the worldwide electricity demand (IEA, 2017). They have become the focal point of extensive campaigns and legal actions to enhance efficiency. As outlined in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014), this situation is predominantly attributed to the fact that buildings rank among the primary contributors to greenhouse gas emissions, primarily because they require substantial energy consumption to fulfill their functions.

Following electricity rationing in 2001, Law 10,295, known as the Energy Efficiency Law (BRASIL, 2001), was enacted. This law established the Executive Branch's responsibility to promote energy efficiency within the country's buildings. In 2009, the National Institute of Metrology, Quality, and Technology (INMETRO) approved the Technical Regulation of the Quality of Energy Efficiency Level of Commercial, Services, and Public Buildings (RTQ-C) (BRASIL, 2010), whose application in federal public buildings became mandatory in 2014. In 2018, the INMETRO Normative Instruction for the Energy Efficiency Class of Commercial Buildings, Services, and Public Buildings (INI-C) replaced RTQ-C.

The INI-C sets forth criteria for categorizing the energy efficiency of buildings. These classifications range from energy class A (indicating the highest efficiency) to E (reflecting the lowest efficiency). The categorization is determined by assessing the primary energy consumption across four systems: building envelope, air conditioning, lighting, and water heating. INI-C offers two distinct evaluation methods. The first is the Simplified Method, which employs a model that relies on artificial neural networks to supply the actual energy consumption. The second method is the Simulation Method, which harnesses computational tools for assessing the building's energy consumption.

This study involves the application of the Simplified Method to ascertain the energy efficiency class of the Air Space Control Department (DECEA) building, a federal public office building situated in the Santos Dumont Airport Complex within the city of Rio de Janeiro. Given that the Simplified Method is a recent issue, it is necessary to conduct testing to provide feedback for enhancements and identify potential limitations. Each application is a study case. Full-text certification reports are inaccessible in the public domain. In addition, comprehensive data

from the building under certification, coupled with an evaluation of the usage of the reference document and subsequent discussions, can contribute to future studies comparing different building labeling regulations or performing critical analysis on them.

2. METODOLOGY

The methodology used in this article is that of the Simplified Method of INI-C (INMETRO, 2018). The INI-C Simplified Method consists of comparing the annual primary energy consumption of a building, in the real condition (data collected from the evaluated building) for the same building, in the reference condition for efficiency class D (using parameters provided by INI-C), for the envelope, air conditioning, lighting and water heating systems (when applicable).

2.1 The DECEA Building

DECEA is located at the Santos Dumont Airport Complex, in the Castelo neighborhood, in Rio de Janeiro, as shown in Figure 1 and Figure 2. The building is located with the longitudinal axis in the North-South direction, with the larger facades facing in the direction East-West, with a total built area of 4,461.55 m², distributed over five floors, as shown in Figure 3.



Figure 1 – Location of the DECEA building



Figure 2 – DECEA building

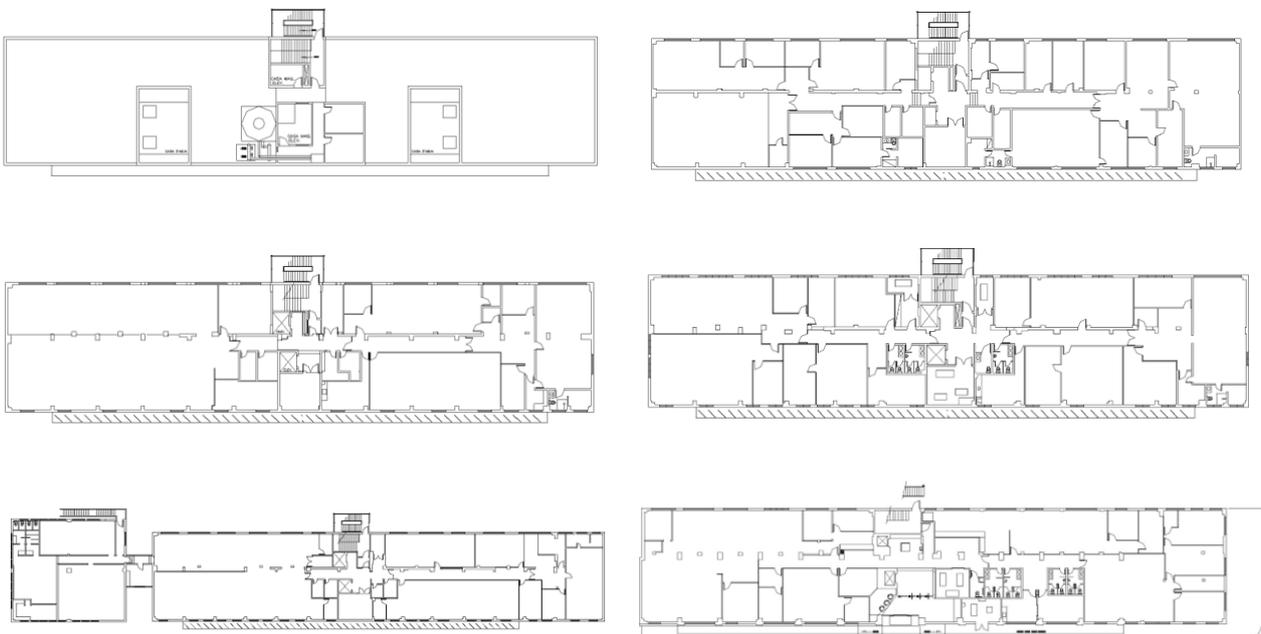


Figure 3 – Roof and floor's building

The external walls facing North, East and South are built with ceramic bricks with eight holes with a density of 1,600 kg/m³, laid in the largest dimension, covered with mortar with a density of 2,000 kg/m³, on the external and internal surfaces, painted in White color. The composition of the West external wall is similar, with the addition of a brise-soleil shading element and the unprotected part was covered with blue ceramic tiles. The roof is composed of a 0.15 cm reinforced concrete slab, with a density of 2,400 kg/m³.

The five floors of the building were divided into 66 thermal zones, 50 artificially conditioned and 16 non conditioned, as shown in Table 1. The unconditioned thermal zones are not evaluated, for purposes of energy classification of the Envelope, in the Simplified Method.

Table 1 — Distribution of thermal zones per floor

Floor	Thermal Zones	Conditioned Zones	Non Conditioned Zones
1	11	9	2
2	19	13	6
3	10	8	2
4	11	8	3
5	15	12	3

For the division of the building into thermal zones, the following assumptions were adopted (INMETRO, 2018):

- separation of the perimeter areas, by solar orientation, from the internal areas;
- depth limited to 4.50 m from the external wall, with a tolerance of ± 1.00 m;
- separation of areas in contact with the ground or with roofs in contact with the outside; and
- separation of areas due to changes in occupation patterns.

2.2 Evaluation of the consumption envelope

The consumption of the DECEA envelope was evaluated in its real and reference condition for class D, using the parameters relevant to its typology (office buildings), according to INI-C, Table A.1 (INMETRO, 2018), for each thermal zone.

The evaluation of the consumption of the building envelope is done by inserting data in the Web interface (available at http://pbeedifica.com.br/redes/comercial/index_with_angular.html#), based on neural networks, to calculate the Thermal Load Density for Refrigeration (DC_{gT} , in kWh/m². year).

This value was multiplied by the area of each thermal zone and added, resulting in the value of the Total Refrigeration Thermal Load (CgT_{REFRIG} , in kWh/year), for the real and reference conditions. This web interface is an integral part of the Method and must be used. Data on thermal transmittance (U) and thermal capacitance (CT) were calculated by the methodology present in the ABNT NBR 15220-2 (ABNT, 2005); the values of the solar absorptance of the walls, were extracted from Dornelles (2008) and the glass data were taken from Annex V (INMETRO, 2013).

2.3 Evaluation of the lighting system

The energy consumption of the lighting system is calculated by Eq.(1):

$$CIL = PI_T \times (h \times N_{ano}) \quad (1)$$

being:

CIL = lighting system consumption, in kWh/year;

PI_T = total installed power, in kW;

h = hours of use of the building;

N_{ano} = occupancy days per year.

The values of h and N_{ano} are taken from INI-C, Table A.1 (INMETRO, 2018).

2.4 Evaluation of the air conditioning system

In the case of systems with different types of equipment (window air conditioning, split system, self-contained, central chilled water, etc.), the consumption of each one must be determined separately. The overall total consumption of the system is given by Eq.(2):

$$CCAT_{(E \text{ or } T)} = S_1 + S_2 + \dots + S_n \quad (2)$$

being:

$CCAT_{(E \text{ or } T)}$ = total electrical or thermal energy consumption of the air conditioning system, in kWh/year;

S_1 = air conditioning system number 1;

S_2 = air conditioning system number 2;

S_n = air conditioning system number n;

2.5 Evaluation of the energy consumption of equipment

The energy consumption of equipment is determined by Eq.(3):

$$CEQ = P_i \times (h \times N_{ano}) \quad (3)$$

being:

CEQ = electrical energy consumption of equipment, in kWh/year;

P_i = installed power of the equipment, in W;

h = hours of use of the building;

N_{ano} = occupancy days per year.

The values of h and N_{ano} are taken from INI-C, Table A.1 (INMETRO, 2018).

2.6 Determination of Energy Efficiency Class

The annual electrical energy consumption, in real and reference conditions, of the lighting and air conditioning systems are calculated by Eq.(4):

$$CTE_E = CIL + CCA_E + CAA_E + CEQ - GE_E \quad (4)$$

being:

CTE_E = total electrical energy consumption, in kWh/year;

CIL = total consumption of the lighting system, in kWh/year;

CCA_E = total consumption of the air conditioning system, in kWh/year.

CAA_E = water heating system consumption, in kWh/year;

CEQ = equipment consumption, in kWh/year;

GE_E = equipment consumption, in kWh/year.

The annual CTE_E values, in real and reference conditions, are divided by 12, for better understanding by building users.

Finally, the CTE_E values, in real and reference conditions, are multiplied by the conversion factor 1.6, to be converted into primary energy.

The percentage reduction in primary energy consumption is calculated by Eq.(5):

$$PRCEP_{REAL-D} = 1 - \frac{CEP}{CEP_{REF}} \times 100 \quad (5)$$

being:

$PRCEP_{REAL-D}$ = percentage of reduction in primary energy consumption in the real condition of the building in relation to its reference condition;

CEP = primary energy consumption of the building in its real condition, in kWh/year;

CEP_{REF} = primary energy consumption of the building in its reference condition, in kWh/year.

To construct Table 2, it is necessary to calculate interval i, using Eq.(6), to determine the limits of each energy efficiency class:

$$i = \frac{(CEP_{REF} \times CRCEP_{D-A})}{3} \quad (6)$$

being:

CEP_{REF} = primary energy consumption of the building in its reference condition, in kWh/year;

$CRCEP_{D-A}$ = consumption reduction coefficient of primary energy from Class D to Class A.

The $CRCEP_{D-A}$ is given in INI-C Table 5 (INMETRO, 2018), based on the form factor and the climate group.

Table 2 — Limits of building energy efficiency class ranges

Class of efficiency	A	B	C	D	E
Upper limit	—	$> CEP_{REF} -3i$	$> CEP_{REF} -2i$	$> CEP_{REF} -i$	$> CEP_{REF}$
Inferior limit	$> CEP_{REF} -3i$	$\leq CEP_{REF} -2i$	$\leq CEP_{REF} -i$	$> CEP_{REF}$	—

The building's energy efficiency class was determined by comparing the primary energy consumption in real conditions with the values for each class.

The energy consumption of the water heating system and the generation of renewable energy are not determined, as the DECEA building does not have these systems.

3. RESULTS

3.1 Thermal loads

For each thermal zone, the thermal load density values for refrigeration (DCgT) were calculated via the web interface, which were multiplied by the areas of the thermal zones, providing the annual total thermal load values for refrigeration, for the real case and the reference one. Table 3 shows the thermal load values, per floor and total for each case.

Table 3— Annual thermal load of the DECEA building

Floor	DCgT Actual Condition (kWh/year)	DCgT Reference Condition (kWh/year)
1	75,400.23	67,113.45
2	102,244.65	123,417.91
3	71,777.03	83,414.66
4	69,137.63	87,001.55
5	76,139.12	92,139.93
Total thermal load consumption (kWh/year)	394,698.66	453,087.50

3.2 Lighting system

The lighting system in the DECEA building consists of 18W LED tube lamps, 9W LED tube lamps, 23W compact fluorescent lamps, 12W LED ceiling lights, Spot lamps 4W and 12W dichroic lamps, with an installed lighting power of 30,533.00 W, for an illuminated area of 4,274.17 m². The annual consumption shown in Table 4 is given by the Eq.(1), with the values of lighting density power (DPI) = 14,1 W/m² for the reference condition, h = 10 hours and $N_{ano} = 260$ days are taken from INI-C, Table A.1 (INMETRO, 2018).

Table 4 — Annual lighting consumption of the DECEA building

	Actual condition	Reference condition
Installed lighting power (kW)	30.53	60.27

Occupancy hours	10
Average working days per year	260

Total lighting consumption (kWh/year)	79,385.80	156,702.00
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3.3 Air-conditioning System

To calculate the efficiency of the air-conditioning system, the equipments are divided into those that are labeled by Inmetro, such as window, split-system and cassette appliances, and those that are not labeled, such as self-contained or central. The systems labeled by Inmetro are classified within their classes, by the Energy Efficiency Coefficient (CEE), according to Figure 4.

Figure 4 — Energy efficiency coefficients — Updated on 08/14/2018

Classes	Coeficiente de eficiência energética (W/W)		
A	3,23	<CEE	
B	3,02	<CEE ≤	3,23
C	2,81	<CEE ≤	3,02
D	2,60	≤CEE ≤	2,81

The equipment was grouped by type and CEE, and the weighted average between the respective CEE and the total amount of equipment was calculated. The resulting value was compared with the values in Figure 4, to determine the energy efficiency class of the system, as shown in Table 5. The DECEA building has 40 split system appliances, 10 of the Hi Wall type and 30 of the Cassete type, with a total cooling capacity of 254.39 kW.

Table 5— Systems regulated by Inmetro — Efficiency class energy

Type	Quantity	CEE
Cassete	5	2.66
Cassete	5	2.71
Hi-Wall	10	2.82
Hi-Wall	1	2.87
Hi-Wall	1	2.96
Hi-Wall	8	3.01
Hi-Wall	3	3.04
Hi-Wall	1	3.20
Hi-Wall	4	3.21
Hi-Wall	1	3.22
Hi-Wall	1	3.24
TOTAL	40	2.91

For systems not labeled by Inmetro, the Coefficient of Performance (COP) of each machine was calculated, which were later grouped by refrigerating capacity to calculate the weighted average between the COP and the total amount of equipment, finding the value of the COP of the System, which will be multiplied by the K Factor of the

Table B.II.25 of the INI-C (INMETRO, 2018), which is 0.48. The DECEA building has 19 direct expansion machines with water condensation, of the self contained type, with different cooling capacities, as shown in Table 6.

Table 6 — System COP

Refrigerating Capacity (TR)	Refrigerating Capacity (kW)	Electric Power (kW)	Quantity	COP (W/W)
25,0	87.92	21.40	1	4.11
24,0	84.40	21.40	1	3.94
15,0	52.75	13.60	7	3.88
12,5	43.96	12.40	2	3.55
10,0	35.17	10.20	6	3.45
7,5	26.38	6.90	2	3.82
TOTAL	893.28		19	3.72

Multiplying the COP value of the system by the K Factor, a corrected COP value of 1.78 was found. The COP value for the reference condition is the Efficiency Class D value for the climate group where the city of Rio de Janeiro is located (GCL 13), given by INI-C Table B.II.23 (INMETRO, 2018), which is equal to 2.64.

The energy consumption of the air conditioning system, for systems labeled and not labeled by Inmetro, in real and reference conditions, is given by divided the thermal load from Table 3 by respective COP, as shown in Table 7, Table 8 and Table 9.

Table 7 — Consumption of the air conditioning system regulated by Inmetro

	Actual condition	Reference condition
Cooling thermal load (kWh/year)	394,698.66	453,087.50
COP (W/W)	2.91	2.60
Total consumption (kWh/year)	135,635.28	174,264.42

Table 8 — Air conditioning system consumption not regulated by Inmetro

	Actual condition	Reference condition
Cooling thermal load (kWh/year)	394,698.66	453,087.50
COP (W/W)	1.78	2.64
Total consumption (kWh/year)	221,740.82	171,624.05

Table 9 — Annual consumption of the air conditioning system

System	Actual condition	Reference condition
Regulated	135,635.28	174,264.42
Unregulated	221,740.82	171,624.05
Total consumption (kWh/year)	357,376.10	345,888.47

3.4 Equipment consumption

The annual consumption of equipment (Table 10) is the result of multiplying the area with the values of equipment density power (DPE) for the reference condition, $h = 10$ hours and $N_{\text{ano}} = 260$ days are taken from INIC, Table A.1 (INMETRO, 2018).

Table 10 — Annual consumption of equipment in the DECEA building

Actual and reference condition	
Installed power density of equipment (W/m ²)	9.7
Area (m ²)	4,274.17
Occupancy hours	10
Average working days per year	260
Total equipment consumption (kWh/year)	107,794.57

3.5 Determination of the general energy efficiency class of the DECEA building

The DECEA building does not have a water heating system, nor a renewable energy generation system. Therefore, these systems are not included in the total annual electricity consumption.

The electrical energy consumption, in the real and reference conditions of the building systems, as well as its total electrical energy consumption (CTE_E), given by the Eq.(4), is shown in Table 11.

Table 11 — Total electrical energy consumption of the DECEA building

	Condition	
	Real	Reference
Envelope	394,698.66	453,087.50
Lighting	79,385.80	156,702.00
Air conditioning system regulated by Inmetro	135,635.28	174,264.42
Air conditioning system not regulated by Inmetro	221,740.82	171,624.05
Equipment	107,794.57	107,794.57
Total consumption (kWh/year)	939,255.13	1,063,472.54

The CTE_E values must be converted into primary energy (CEP), by multiplying the electrical to primary energy conversion factor, which is 1.6 (INMETRO, 2018). Table 12 presents the primary energy values of the DECEA building per year and per month, for real and reference conditions.

Table 12 — Primary energy consumption

	Condition	
	Real	Reference
Annual consumption (kWh/year)	1,502,808.21	1,701,556.06
Monthly consumption (kWh/month)	125,234.02	141,796.34

The percentage of savings in primary energy in relation to Class D is calculated by Eq.(5) and is equal to 11.88%.

The range of scale classes is calculated by Eq.(6) and is equal to 181,499.31 kWh/year, with the value of the primary energy consumption reduction coefficient from class D to class A, given by INI-C Table 5 (INMETRO, 2018), from shape factor and climate group (GCL 13), equal to 0.32.

Replacing the values of primary energy consumption (CEP_{REF}) and the range of classes i in Table 2, the Efficiency Classes Table was constructed (Table 13):

Table 13 — Table of global energy efficiency classes

Efficiency class	A	B	C	D	E
Upper limit	-	1,157,058.12	1,338,557.44	1,520,056.75	1,701,556.06
Inferior limit	1,157,058.12	1,338,557.44	1,520,056.75	1,701,556.06	-

Comparing the primary energy consumption value in the real condition with the values in Table 13, it is concluded that the DECEA building is included in Class C for energy efficiency.

4. CONCLUSIONS

This study shares the application of the Simplified Method to ascertain the energy efficiency class of a public office building. This kind of information is limited in the literature since certification reports have restricted access.

The DECEA building's classification as a C for energy efficiency is a result of being evaluated under criteria that were not in place during its original design and construction. It is a common scenario for older buildings to be evaluated against newer, more stringent energy efficiency standards. While certain aspects like lighting and air conditioning systems can be updated to meet higher efficiency standards, improving the building envelope's performance might require costly renovations.

Updating the air conditioning systems or making significant changes to the building envelope to improve its energy efficiency rating could be economically challenging. This is a common dilemma faced when attempting to retrofit older buildings to comply with newer energy efficiency standards. The cost implications for such upgrades can sometimes outweigh the energy savings achieved, making it economically unfeasible.

However, the obligation to evaluate and certify federal public buildings for energy efficiency serves a larger purpose. By assessing these buildings and forming a database, it provides a comprehensive picture of their energy efficiency levels. This data, when aggregated, can contribute to the improvement of legislation and standards for energy efficiency in buildings. It allows policymakers and stakeholders to understand the existing status quo and work towards better, more realistic standards that balance energy efficiency gains with economic feasibility.

The information gathered from these evaluations helps in shaping future regulations and guidelines. It enables a more informed approach, considering the practical challenges faced in updating older buildings without imposing excessive financial burdens.

In summary, while the cost of improving the energy efficiency of older buildings can be a hurdle, the evaluation and certification process for federal buildings play a vital role in forming a database. This data can significantly influence future legislation, aiming to strike a balance between energy efficiency improvements and economic feasibility for building upgrades.

5. ACKNOWLEDGEMENTS

We thank DECEA for permission to use the building as a case study.

6. REFERENCES

- ABNT NBR 15220-2: *Thermal performance of buildings: Part 2: Method for calculating thermal transmittance, thermal capacity, thermal delay and solar factor of building elements and components*. Rio de Janeiro, 2005a.
- ANSI/ASHRAE/IESNA, 2004. *Standard 90.1 – 2004 Energy Standard for Buildings Except Low-Rise Residential Buildings – SI Edition*. ASHRAE, Atlanta.
- ASHRAE, 2004. *User's Manual ANSI/ASHRAE/IESNA Standard 90.1 – 2004 Energy Standard for Buildings Except Low-Rise Residential Buildings*. ASHRAE, Atlanta.
- Borg, Nils E Janssen, Rod., 2009, "Existing buildings are the key to fighting climate change." http://www.eceee.org/press/eceee_and_industry. Accessed 2 november 2009.

- Brasil, 2001. *Law n° 10.295, 17 october 2001*. Brasília, 2001. <http://www.inmetro.gov.br/qualidade/lei10295.pdf>. Accessed 30 de may de 2009.
- Brasil, 2001. *Decree Law n° 4059, 19 december 2001*. <http://www81.dataprev.gov.br/sislex/paginas/23/2001/4059.htm>. Accessed 30 may 2009.
- Dornelles, Kelen A., 2008, "Solar absorbency of opaque surfaces: determination methods and database for acrylic and PVA paints.", Unicamp, Campinas.
- EPE, 2018, *Electric Energy Statistical Yearbook 2018, Final Report* (in Portuguese), Empresa de Pesquisa Energética EPE, Rio de Janeiro.
- INMETRO, 2018, *Inmetro Normative Instruction for the Energy Efficiency Classification of Commercial Services and Public Buildings (INI-C)*. INMETRO, Rio de Janeiro.
- INMETRO, 2013, *Conformity Assessment Requirements (RAC)*. INMETRO, Rio de Janeiro.
- INMETRO, 2010. *Technical Quality Requirements for the Energy Efficiency Level of Commercial, Service and Public Buildings (RTQ-C)*. INMETRO, Rio de Janeiro.
- IPCC. AR 5 Climate Change 2014: mitigation of climate change. Intergovernmental Panel on Climate Change. IPCC, New York, https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter9.pdf>. Accessed 15 december 2018.
- IEA. Energy Technology Perspectives 2017INTERNATIONAL ENERGY AGENCY. Energy Technology Perspectives 2017. <<https://www.iea.org/buildings/>>. Accessed: 02 dec 2018

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