Analysis of Control Strategies for Energy Performance Optimization for Educational Buildings: Comparison of Two Kindergartens in the Municipality of Bolzano, Italy

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Abstract

In the wake of the worsening of the energy crisis in winter 2022, several public administrations in Italy recommended simple energy systems operation control measures, to be implemented in the local building stock to reduce energy consumption and produce economic savings in the short term. In particular, in the municipality of Bolzano, Italy, these measures ranged from lowering the heating setpoint temperature, implementing systems setbacks or ON/OFF setting and reducing ventilation rates. However, these measures were applied to all buildings, without distinguishing vintage and type, with the risk of worsening the indoor environmental quality (IEQ) in some of them. In this context, this study focuses on the analysis of two kindergartens of dated and recent construction in the city of Bolzano, with the aim of evaluating the applicability of the proposed energy-saving control measures on buildings representative of "old" and recent constructions. Results proved the importance of carefully considering building specific features to design effective HVAC systems operation measures, able to optimize the systems performance and guarantee adequate IEQ conditions.

1. Introduction

In Italy, the worsening of the energy crisis since winter 2022 has increased the urgency to improve the energy performance of the local building stock, which often have dated HVAC systems and operation inefficiencies. Faced with this situation, several public administrations recommended relatively simple, general control measures to be implemented in their own buildings with the aim of limiting energy consumption and producing economic savings in the short term, avoiding soaring energy bills. In the municipality of Bolzano, suggested measures consisted in (i) lowering heating setpoint temperatures of 2 °C, (ii) implementing temperature setbacks or systems ON/OFF setting, and (3) reducing ventilation rates. However, the proposed HVAC systems control measures were implemented regardless of the building type, i.e., function, construction period, envelope and energy systems, with the risk of worsening the thermal comfort conditions for indoor occupants.

Given these premises, several studies can be found in the literature proving the efficacy of energy systems control strategies in optimizing buildings' energy consumption, among which it is worth mentioning the works of De Santoli et al. (2014), Hong et al. (2014), and Wang et al. (2015). Furthermore, great effort has been dedicated to identifying optimal performance enhancement solutions. For instance, Hoyt et al. (2015) found that, if implemented correctly, a widened thermostat setpoint range results in significant energy savings, even though they largely depend on the type of heating or cooling system.

That being said, to the authors' knowledge, limited attention has been given to the actual effectiveness and the impacts of general basic operation control measures when applied to any type of building, regardless of its features and without a proper prior evaluation, which may happen in an "emergency" situation. In this context, the aim of this study is the assessment of the applicability of the proposed HVAC systems operation measures to both recently constructed and dated public buildings, to determine the extent of energy savings and the buildings' ability to maintain acceptable indoor thermal comfort conditions.

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2. Methodology

2.1 Case Studies

For the analysis, two public kindergartens in the municipality of Bolzano were selected as case studies. In detail, a recently constructed (A) and a relatively dated kindergarten (B) were chosen.

As for Bolzano, the city is located in a valley at around 250 m above sea level and is characterised by a semi-continental climate, with cold winters and hot summers. Since Bolzano belongs to climate zone E according to the Italian national classification, the heating season starts on October 15th and ends on April 15th.

Considering in detail the two case-study buildings, building A was built in 2009, it has a rough L-shape with a convex side facing Nort-East, two storeys above ground and an underground floor. The total heated surface per floor is 667.53 m² and 576.93 m² for the ground and the first floors respectively, while 339.88 m² for the underground floor. The underground level includes a conditioned space, hosting kitchen, inventories and changing rooms for school employees, and an unconditioned garage area. The ground and first floors host classrooms, teachers' rooms and restrooms. A staircase placed at the entrance of the building connects the three storeys and a double-height colonnade shades the mostly glazed west façade. The building is representative of recent constructions with its well-insulated envelope in compliance with local requirements.

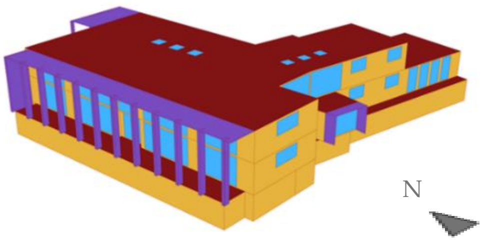

Fig. 1 – Building A south-west view

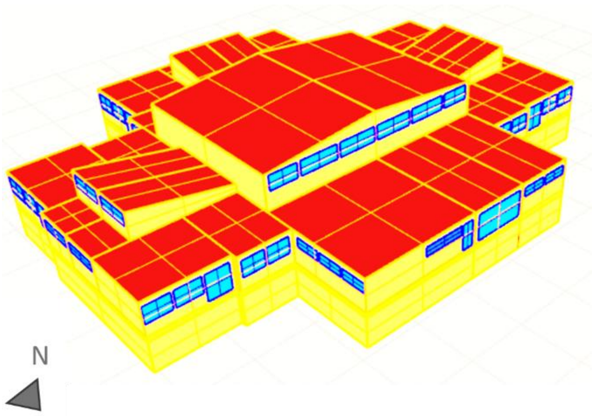

Fig. 2 – Building B south-east view

On the other hand, building B was built in 1971, has an almost square shape, one storey above ground and an underground floor. While the ground floor hosts the kindergarten with a total net heated surface of 1355.47 m², the underground does not belong to it and is not part of the analysis. In detail, kindergarten B is divided into six "sections" blocks, each block is characterised by a classroom, an adjacent "lunchroom" and a restroom area. The six blocks, together with the "service" area (hosting the kitchen, the storage and the personnel's changing rooms), the administration office, and the entrance are developed around a double-high central atrium. The six restroom areas present a double-high part, as well with a gabled roof. The building is provided with external roller shades protecting the glazed surfaces, except for the atrium ones and the restrooms upper windows. The building is representative of partially renovated dated constructions, with uninsulated external walls with retrofitted triple-glazed windows and a recently retrofitted green roof.

Both buildings are provided with a condensing boiler as heating system, serving radiant floor panels as heating terminals in building A and radiators in B. The regular heating setting features a temperature setpoint of 21 °C kept constant for the entire heating season (with no setback or system on-off setting). Furthermore, both kindergartens rely on natural ventilation only, no mechanical ventilation or cooling system are present.

2.2 Buildings Energy Models

The buildings' detailed energy models were created via Rhinoceros3D software, with Grasshopper and Honeybee plugins, Window LBNL and EnergyPlus simulation program. While the model for building A was developed in previous research, the one for building B was created on purpose for this analysis. Model A was calibrated and validated against indoor dry-bulb temperature data recorded during monitoring campaigns conducted in 2019. Model B was calibrated and validated against indoor dry-bulb temperature data recorded during monitoring campaigns conducted since February 2023. In detail, the months of December 2023 and February 2024 were used for calibration and validation respectively.

In both buildings, the number of occupants and daily occupancy schedules were set based on the school administration's information and technical standards typical values (ASHRAE, 2009). The infiltration rate was defined during the calibration and validation process, while natural ventilation was set with the same rates and schedules in both buildings. Heating system installed capacity limits were set based on the buildings' design data provided by the public administration of Bolzano.

Model A is characterized by 4 thermal zones (*TZs*), corresponding to the heated ground (*P0*), first (*P1*) and underground (*P-1*) floors and the unheated garage area. Model B has 23 TZs, among which the unheated entrance and the underground level (*P-1*), in which constant heating at a setpoint temperature of 20 °C was set.

2.3 Control Strategies

Four main control strategies were defined and tested in EnergyPlus on both case-study buildings in a total of eight scenarios (from 1 to 4.2).

2.3.1 Baseline scenario

The baseline Scenario (0) is representative of the standard building operation, with (i) a constant heating setpoint temperature (*T SP*) of 21 °C for the entire heating season and (ii) no setback or system "off" setting.

2.3.2 Scenario 1: Lower heating setpoint temperature

This scenario is characterised by (i) a lower constant heating setpoint temperature of 19 °C and (ii) no setback or system "off" setting in all heated TZs.

2.3.3 Scenario 2: Heating schedule settings

This strategy consists in an ON/OFF heating schedule setting applied to all heated TZs over the entire heating season, considering daily occupancy, as well as weekends and holidays: ON setting from Monday to Friday during daily occupancy time, OFF setting at weekends and on holidays. A 21 °C temperature setpoint was maintained as in the baseline scenario.

Two alternatives were considered: (i) the first one (Scenario 2.1) characterised by a single daily schedule for all TZs; (ii) the second one (Scenario 2.2) including differentiated daily schedules among the TZs (Table 1).

2.3.4 Scenario 3: Combination of lower heating setpoint temperature and heating schedule settings

In Scenario 3.1, Scenarios 1 and 2.2 were combined, applying a temperature setpoint of 19 °C and differentiated heating schedules among the different TZs. In Scenario 3.2, a temperature setback of 16 °C has been introduced during daytime hours: from 8:00 to 11:00 and from 14:00 to 17:00 in P-1 of building A, while from 8:00 to 10:00 and from 14:00 to 17:00 in the service area of building B.

2.3.5 Strategy 4: Preheating

Scenario 4.1 consists in preheating every day all TZs two hours before daily activities start. On the other hand, Scenario 4.2 integrates the measures of 4.1 with a preheating of the whole building three hours before the activities start on the first day after holidays "off" setting.

2.4 Energy Analysis and Thermal Comfort Evaluation

The energy simulations were carried out via EnergyPlus software and results were analysed in terms of heating energy consumption and indoor air temperature. First, the comparison at building level among results obtained in the different scenarios was carried out, accounting at the same time for thermal comfort levels following the implementation of the considered strategies; then, the comparison between the two buildings in terms of energy savings obtained in the different scenarios was performed. The thermal comfort evaluation was carried out using as reference standard EN 16798-1 (CEN, 2019). In this paper, the thermal environment analysis results, obtained in the main representative scenarios, for P1 TZ of building A and the North-West classroom (W1A TZ) of building B, have been reported, since these spaces are among the main buildings' TZs having the strictest IEQ requirements (as they host children-dedicated spaces) and with the most critical thermal comfort conditions. In detail, the analysed metrics are the following: (i) the specific monthly and annual heating energy needs in kilowatthours per square meter, (ii) the energy savings percentage obtained by applying each control strategy with respect to the baseline scenario, and (iii) the indoor dry bulb temperature in degrees Celsius.

Table 1 – Scenario 2 settings

Scenario	Thermal Zone	Thermostat ON/OFF	Daily Schedule From	To	
2.1	All Heated TZs	ON	08:00	18:00	Heating Season Schedule
		OFF	18:00	08:00	
2.2	P-1 (Building A) - Service Area (Building B)	ON	07:00	08:00	Heating Season Schedule
		OFF	08:00	11:00 (B) / 10:00 (A)	
		ON	11:00 (B) / 10:00 (A)	14:00	
		OFF	14:00	17:00	
		ON	17:00	18:00	
		OFF	18:00	07:00	
	P0 & P1 (Building A) - Six "sections" blocks (Building B)	ON	08:00	18:00	Heating Season Schedule
		OFF	18:00	08:00	
	Atrium & Office (Building B)	ON	08:00	16:00	Heating Season Schedule
		OFF	16:00	08:00	

3. Results and Discussions

Considering building A, as it is possible to observe in Table 2 and Fig. 3, despite the relevant energy savings of about 50 %, strategies from 3.1 to 4.2 are unsuitable as they do not guarantee acceptable indoor thermal comfort levels. Indeed, as shown in Fig. 3, in these scenarios, temperatures fall below 18 °C for more than 10 % of the school-time hours in the month of January.

On the other hand, strategies from 1 to 2.2 allow for relatively acceptable indoor thermal comfort conditions with lower, but still substantial, energy savings reaching 33 % in Scenario 1. As for building B, from Table 3 and Fig. 4 it is possible to observe that strategies 3.1 and 3.2 are unable to guarantee adequate indoor thermal comfort conditions, while strategies 1 and 4.2 allow for relevant energy savings of 33 % and 46 % respectively, and relatively acceptable indoor thermal comfort levels in most of the heated thermal zones. Indeed, in the considered North-West classroom, in both scenarios, temperatures remained equal or above 19 °C most of the time in the coldest months, reaching peaks above 21 °C in the milder months of March, April and October.

Table 2 – Monthly and annual total heating load and annual energy savings percentage of each control strategy with respect to the baseline scenario for building A

Building A - Total Heating Load [kWh/m²]								
Month	**Scenario**							
	0 Baseline	**1**	**2.1**	**2.2**	**3.1**	**3.2**	**4.1**	**4.2**
January	5.85	4.57	4.74	4.56	3.72	3.72	3.81	3.81
February	3.42	2.26	2.54	2.51	1.71	1.71	1.70	1.71
March	2.54	1.24	2.44	2.42	1.27	1.27	1.27	1.27
April	0.56	0.17	0.41	0.40	0.13	0.13	0.13	0.13
October	0.52	0.16	0.39	0.35	0.10	0.10	0.10	0.10
November	3.14	1.73	2.45	2.38	1.38	1.38	1.38	1.38
December	5.70	4.41	3.25	3.18	2.48	2.48	2.50	2.50
Total Annual	21.72	14.55	16.21	15.78	10.80	10.80	10.89	10.90
Specific Total Annual Heating Load Ratio with respect to the Baseline	-	67%	75%	73%	50%	50%	50%	50%
Savings Percentage of each Control Strategy with respect to the Baseline	-	33%	25%	27%	50%	50%	50%	50%

Table 3 – Monthly and annual total heating load and annual energy savings percentage of each control strategy with respect to the baseline scenario for building B

Building B – Total Heating Load [kWh/m²]								
Month	**Scenario**							
	0 Baseline	**1**	**2.1**	**2.2**	**3.1**	**3.2**	**4.1**	**4.2**
January	8.05	6.17	6.81	6.45	5.26	5.26	5.24	5.26
February	4.39	2.78	3.89	3.77	2.63	2.63	2.56	2.56
March	1.80	0.52	1.96	1.95	0.61	0.61	0.60	0.60
April	0.28	0.00	0.23	0.24	0.00	0.00	0.00	0.00
October	0.29	0.00	0.27	0.26	0.00	0.00	0.00	0.00
November	4.87	3.04	4.37	4.19	2.76	2.76	2.71	2.71
December	7.35	5.52	4.86	4.65	3.63	3.63	3.52	3.52
Total Annual	27.02	18.03	22.38	21.51	14.89	14.89	14.64	14.65
Specific Total Annual Heating Load Ratio with respect to the Baseline	-	67%	83%	80%	55%	55%	54%	54%
Savings Percentage of each Control Strategy with respect to the Baseline	-	33%	17%	20%	45%	45%	46%	46%

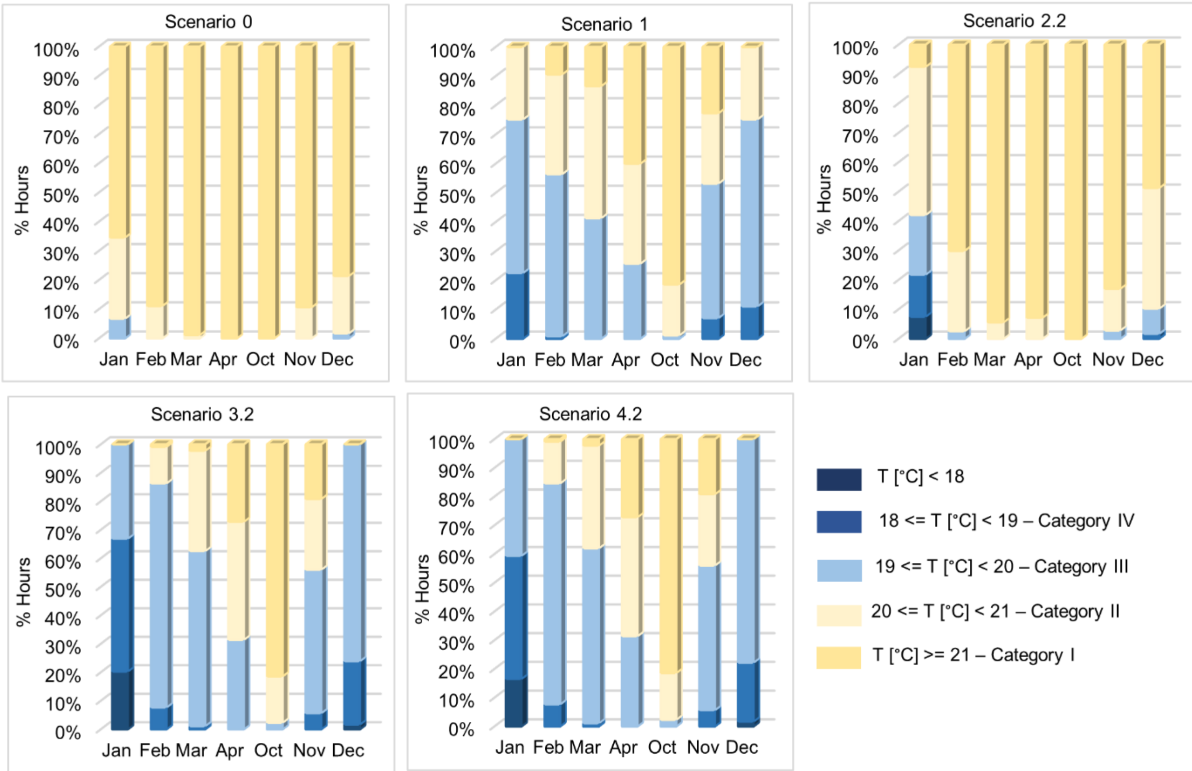

Fig. 3 - Building A – First floor: percentage of monthly school-time hours per temperature interval for the different scenarios (EN 16798-1:2019)

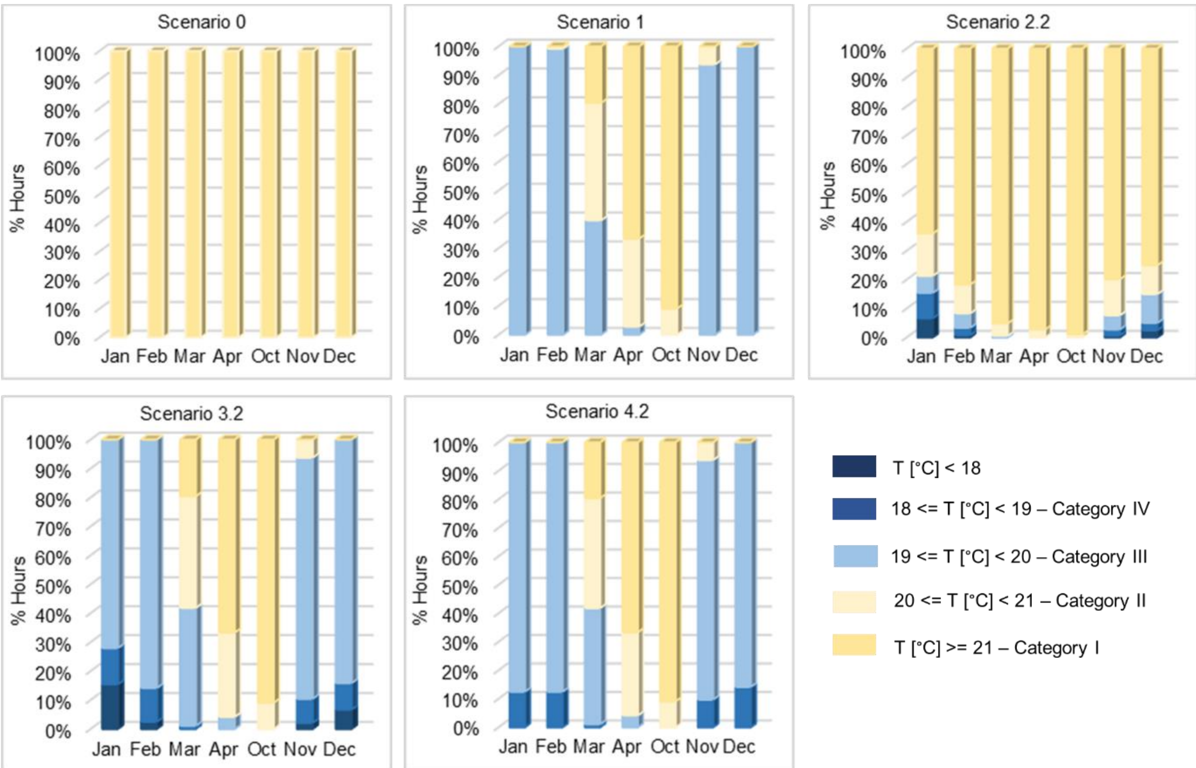

Fig. 4 - Building B – North-West Classroom: percentage of monthly school-time hours per temperature interval for the different scenarios (EN 16798-1:2019)

3.1 Energy Savings Comparison

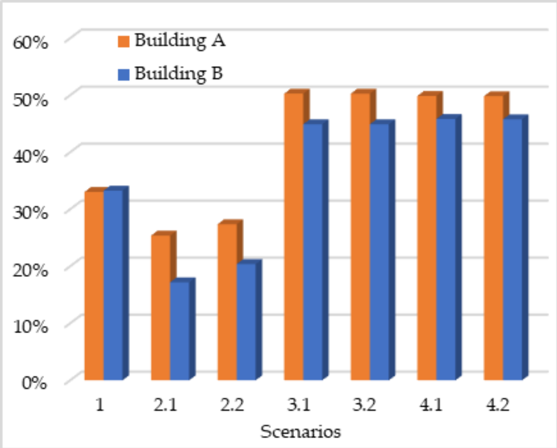

Fig. 5 - Heating energy savings percentage of each control strategy with respect to the baseline in the two case-study Buildings

Higher energy savings were registered in building A compared to B in almost all scenarios (see Fig. 5), except Scenario 1 with savings of about 33 % in both buildings. On the other hand, the energy savings trend resulted almost comparable in both buildings:

- The highest savings were obtained by combining the ON/OFF setting strategy with the temperature setpoint lowering in Scenarios from 3.1 to 4.2.
- The lowest savings were registered with the implementation of the ON/OFF strategies in Scenarios 2.1 and 2.2.
- The best compromise between energy savings and relatively acceptable indoor thermal comfort levels was reached in both buildings in Scenario 1, with an energy savings percentage of almost 33 %.

4. Conclusions

This study has assessed the applicability of basic energy systems operation measures, which were recommended by several public administrations in Italy, in the wake of the worsening of the energy crisis in 2022, to limit energy consumption and avoid spiking energy bills in the local public building stock. For the assessment, two public kindergartens of dated and recent construction, in the municipality of Bolzano (Italy), were considered as case studies, the energy performance simulations were performed and the energy savings and indoor thermal comfort after the implementation of the proposed measures were analysed.

Results demonstrated that HVAC systems operation control measures should not be implemented regardless of the building type, as buildings of different typology, i.e., function, construction period, envelope and energy systems, show different responses and behaviours.

Thus, the following considerations may be made:

- Relatively simple operation control measures allow us to obtain significant energy savings in both recently constructed and dated building, but, at the same time, they can lead to a worsening of the indoor thermal environment.
- It is difficult to reach and maintain acceptable indoor thermal comfort conditions when lowering the heating system setpoint temperature by 1-2 °C and applying ON/OFF setting or even temperature setbacks at the same time. This occurs especially when relying on natural ventilation only, as it could be observed in scenarios from 3.1 to 4.2 in both case-study buildings.
- When lowering the heating setpoint temperature by 1-2 °C with respect to the recommended design one, continuous heating at constant setpoint is needed to maintain acceptable thermal comfort levels but may not be sufficient to guarantee these conditions in all thermal zones especially in the most dated buildings (Scenario 1).
- With the heating system ON/OFF setting only, it is difficult to reach and maintain adequate indoor thermal comfort conditions over the entire occupancy period, as it resulted in Scenarios 2.1 and 2.2 of both case-study buildings.

Some final design suggestions for the retrofit of both high-performance, recent constructions and more dated, poorly performing buildings are reported below:

- Building envelope typology and HVAC system must be carefully considered for a proper planning of energy systems operation control strategies.
- Mechanical ventilation is needed to provide the required air changes and avoid excessive heat losses during the heating season.

- A differentiation of the heating setpoint setting between the coldest fall-winter months, from December to February, and the months of October, November, March and April may be considered, as a lower setpoint temperature and no temperature setback are required in these milder fall-winter months.

To conclude, well-designed and carefully evaluated energy retrofit measures remain of primary importance to properly optimize the energy performance of both dated and recent constructions and guarantee adequate IEQ levels.

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References

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 2009. "*ASHRAE Handbook: Fundamentals*."

De Santoli, L., F. Fraticelli, F. Fornari, and C. Calice. 2014. "Energy performance assessment and a retrofit strategies in public school buildings in Rome." *Energy and Buildings* 68: 196-202. https://doi.org/10.1016/j.enbuild.2013.08.028

European Committee for Standardization (CEN). 2019. "*EN 16798-1:2019. Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics-Module M1-6.*"

Hong, T., L. Yang, D. Hill, and W. Feng. 2014. "Data and analytics to inform energy retrofit of high performance buildings." *Applied Energy* 126: 90-106. https://doi.org/10.1016/j.apenergy.2014.03.052

Hoyt, T., E. Arens, and H. Zhang. 2015. "Extending air temperature setpoints: Simulated energy savings and design considerations for new and retrofit buildings." *Building and Environment* 88: 89-96. https://doi.org/10.1016/j.buildenv.2014.09.010

Wang, Y., J. Kuckelkorn, F.-Y. Zhao, D. Liu, A. Kirschbaum, and J.-L. Zhang. 2015. "Evaluation on classroom thermal comfort and energy performance of passive school building by optimizing HVAC control systems." *Building and Environment* 89: 86-106. https://doi.org/10.1016/j.buildenv.2015.02.023