Energy Saving Achieved with Adaptive Setpoint Temperatures Based on EN16798-1: Application of the Category III

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Abstract. Climate change is one of the main problems of the society of the 21st century. High emissions of Greenhouse Gases (GHG) are generating more and more extreme living conditions, so GHG emissions should be reduced. Regarding buildings, their high energy consumption is mainly responsible for the contributions of GHG to the atmosphere. Ambitious goals for reducing GHG emissions have therefore been established by 2050. This study analyses the potential of the energy saving achieved using adaptive setpoint temperatures. These setpoint temperatures based on different thermal comfort models as energy conservation measures have been analysed in previous studies. However, the European Committee for Standardization has recently published a new standard. The new European thermal comfort model, the standard EN16798-1, is therefore used in this study. A total of 10 building models in southern Spain were analysed using EnergyPlus. The energy consumption obtained with adaptive setpoint temperatures was compared to that obtained using a static thermal comfort model. The results reflected the potential for the energy saving obtained by using adaptive setpoint temperatures in warm climatic zones.

Keywords: Consumption · Adaptive setpoint temperatures · Building · HVAC system · Warm climate

1 Introduction

The existing building stock in Europe has a deficient energy behaviour [1, 2]. This behaviour is generated greater greenhouse gas emissions by the existing buildings [3, 4]. To reduce this consumption, a greater implementation of nearly zero energy building (nZEB) is essential. According to the Directive 2010/31/UE, all countries of the European Union must design new buildings or restorations as per the criteria of nZEB from 2020 [4]. Although the designs appropriate to reach nZEB are easy to be implemented in cold climates, their implementation is more complex in warm regions [5].

To ease this transition, many research studies have been developed in recent years to reduce the energy consumption in these regions. It is on this point where the implementation of adaptive thermal comfort models in the use of HVAC systems is reaching

A. Rotaru (Ed.): CRIT-RE-BUILT 2019, SSGG, pp. 458–466, 2021.
https://doi.org/10.1007/978-3-030-61118-7_37

important values of energy saving. Adaptive thermal comfort models are based on the capacity of adaptation of the human being under external variations so that the limits in which the environmental temperature could be adapted to be under thermal comfort conditions. The use of an approach based on this principle leads to important energy savings if they are compared to the tradition criteria of using HVAC systems (i.e., based on the use of static setpoint temperatures). In this regard, some research studies show the savings that could be reached:

- Barbadilla-Martín et al. [6] used as setpoint temperatures the neutral temperatures of a comfort model for mixed-mode buildings. Such model was designed for the climate of Seville. The energy consumptions obtained by using old setpoint and adaptive temperatures were compared (old setpoint temperatures were 22.3 °C and 23.5 °C, whereas adaptive temperatures were 21.5 °C and 24 °C). Both energy savings of 27.5% in cooling and of 11.4% in heating were obtained.
- Sánchez-Guevara Sánchez et al. [7] analysed 3 buildings of social dwellings located in 3 different cities (Avila, Madrid, and Seville). The authors used setpoint temperatures monthly varying by applying the adaptive thermal comfort model, thus achieving an energy saving between 20 and 80% in buildings.
- Sánchez-García et al. [8] analysed the application of daily adaptive setpoint temperatures according in a case study located in the same cities of the study by Sánchez-Guevara Sánchez et al. [7], thus achieving a saving in the energy consumption between 10 and 46% with respect to the recommendations of the Spanish regulation on setpoint temperatures in this type of buildings.

Regarding to adaptive thermal comfort models, there is a wide variety of standards that develop models adapted to each region, such as the EN 15251:2007 standard [9] and the EN 16798-1:2019 standard [10]. The EN 15251:2007 standard was the first European adaptive thermal comfort standard. Nevertheless, this standard has been updated with the EN 16798-1:2019 standard. Such standard sets 3 different categories (I, II, and III), giving recommendations according to the level of expectation of the occupant and the state of the building. Upper and lower limits are established for the operative temperature in each category, and the higher the category, the higher the range of tolerance of comfort limits. For the application of the thermal comfort model, the running mean outdoor temperature (θ_{rm}) (Eq. 1)) must be between 10 and 30 °C. Limits are calculated by using linear correlations according to θ_{rm} (Eqs. (2 and 3)).

$$\theta_{rm} = \left(\theta_{ext,d-1} + 0.8\theta_{ext,d-2} + 0.6\theta_{ext,d-3} + 0.5\theta_{ext,d-4} + 0.4\theta_{ext,d-5} + 0.3\theta_{ext,d-6} + 0.2\theta_{ext,d-7}\right)/3.8 \tag{1}$$

$$Upperlimit(CategoryIII) = 0.33 \cdot \theta_{rm} + 22.8 \tag{2}$$

$$Lowerlimit(CategoryIII) = 0.33 \cdot \theta_{rm} + 13.8 \tag{3}$$

Regarding EN 16798-1:2019, most research studies are based on the thermal comfort limits of category III from EN 15251:2007. The modification leading to the new standard was related to the increase of the range of θ_{rm} for the lower limit and to the variation of correlations for the calculation of limits. It is therefore possible that the application of the new standard means a variation in the building energy consumption. For this reason, this research applied adaptive setpoint temperatures to a set of 10 different case studies. These case studies were located in Seville as it is one of the main cities on which the previous research studies have been focused to analyse the adaptive models [8, 11]. The use of a regular usage profiles of HVAC systems in the country allowed the viability of using these measures to be determined.

2 Methodology

To study the effect caused by adaptive setpoint temperatures in different geometries, 10 different building typologies were modelled (see Fig. 1). These case studies are used as various studies obtained through a positive experience [12–14].

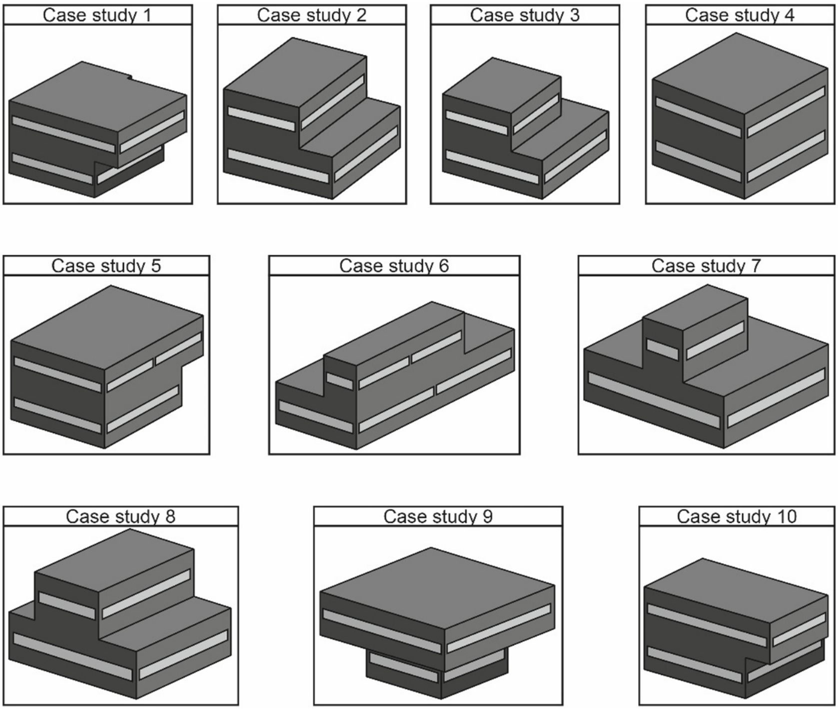

Fig. 1. Case studies designed for the research

The case studies were designed with different single-family dwelling typologies. All geometries presented the same number of floors and the glazing percentage was 25% in all façades. Also, the case studies do not have shading elements.

Regarding the thermal properties, designs appropriate to the building stock in Seville were determined. Table 1 includes the thermal properties of the different envelope elements. As HVAC system, a heat pump with a Coefficient of Performance (COP) of 2.10 and with an Energy Efficiency Ratio (EER) of 2.00 was designed in all case studies.

Table 1. Thermal properties of the envelope of the case studies.

Element	Thermal transmittance [W(m^{2}K)]
Façade	0.637
Floor	0.800
Ceiling	0.661
Window	2.761

The simulation process of the case studies was performed with EnergyPlus through DesignBuilder. The EnergyPlus weather file of Seville was obtained with METEONORM. Regarding the usage and load profiles of the system, the specifications of the Spanish Building Technical Code (in Spanish, CTE) were considered [15]. In such standard, the residential usage profile typical for Spain is established, including both the load profiles (see Fig. 2) and the setpoint temperatures for these buildings (see Table 2). Regarding the setpoint temperatures, as this study aimed at assessing the energy saving obtained by using adaptive setpoint temperatures according to the category III from EN 16798-1, the static profile of the CTE was adapted to the standard (see Table 2): the setpoint temperature of the adaptive model was calculated according to the variation of the external temperature by using Eqs. (1) and (2), whereas it did not vary in the static model. In the adaptive model, when the adaptive thermal comfort model could not be applied (e.g., when the external temperature was lower than 10 °C), setpoint temperatures were obtained by extending the limit values in the boundary conditions of the adaptive model.

The results obtained in the static model will therefore be useful to have a reference value of the energy consumption associated with the case studies according to the building standard in Spain. Obtaining differences in the energy consumption of the adaptive model shows the possible savings achieved by adaptive models.

3 Results and Discussion

To analyse the energy saving, a total of 20 different simulations were performed in EnergyPlus: 10 for the static model and 10 for the adaptive model. Results of monthly and annual energy consumption were obtained by these simulations. Firstly, the results of monthly energy consumption are discussed. As can be seen in Fig. 3 and in Table 3, the use of adaptive setpoint temperatures achieved important savings in the monthly energy consumption. As for the heating energy consumption, such consumption decreased between 0.02 and 1.54 kWh/m^2, with a percentage deviation between 44.71 and 100%. As for the

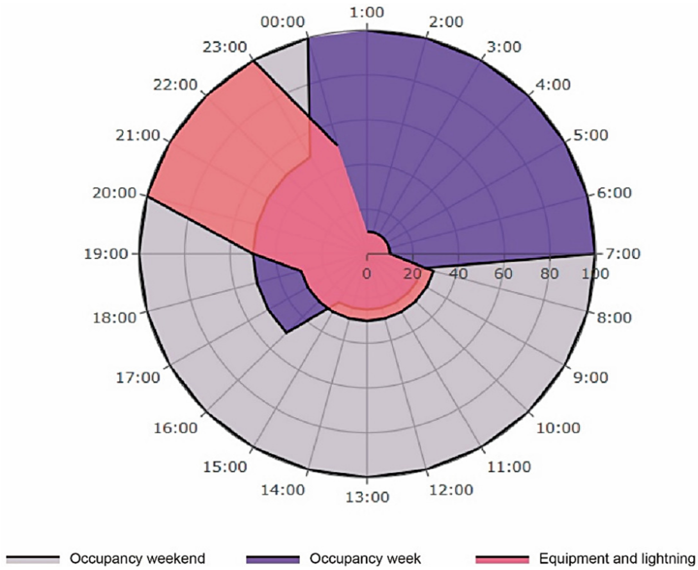

Fig. 2. Radar chart with the hourly profiles of equipment, lightning, and occupancy. 100% of equipment and lighting corresponds to an hourly load of 4.4 W/m^2 and 100% of occupancy corresponds to an hourly load of 3.23 W/m^2.

Table 2. Setpoint temperatures used in the static and adaptive models.

Model	Standard	Limit	Range θ_{rm} [°C]	Setpoint temperature [°C]								
				Jan.–May			June–Sep.			Oct.–Dec.		
				24–7	8–15	16–23	24–7	8–15	16–23	24–7	8–15	16–23
Static	CTE	Upper	all	–	–	–	27	–	25	–	–	–
		Lower	all	17	20	20	–	–	–	17	20	20
Adaptive	EN 16798-1 Category III	Upper	(-∞,10)	–	–	–	26.1	–	26.1	–	–	–
			[10,30]	–	–	–	(1)	–	(1)	–	–	–
			(30,∞)	–	–	–	32.7	–	32.7	–	–	–
		Lower	(-∞,10)	17.1			–	–	–	17.1		
			[10,30]	(2)			–	–	–	(2)		
			(30,∞)	23.7			–	–	–	23.7		

(1) $0.33 \cdot \theta_{rm} + 22.8$; (2) $0.33 \cdot \theta_{rm} + 13.8$

cooling energy consumption, the energy saving ranged between 5.27 and 10.31 kWh/m^2, with a percentage deviation between 51.74 and 67.78%.

The use of adaptive setpoint temperatures implied a considerable decrease in the cooling energy consumption. In this sense, although the percentage decrease of the energy consumption was lower in cooling than in heating, the low values associated with the heating consumption of the static model caused that the percentage deviation

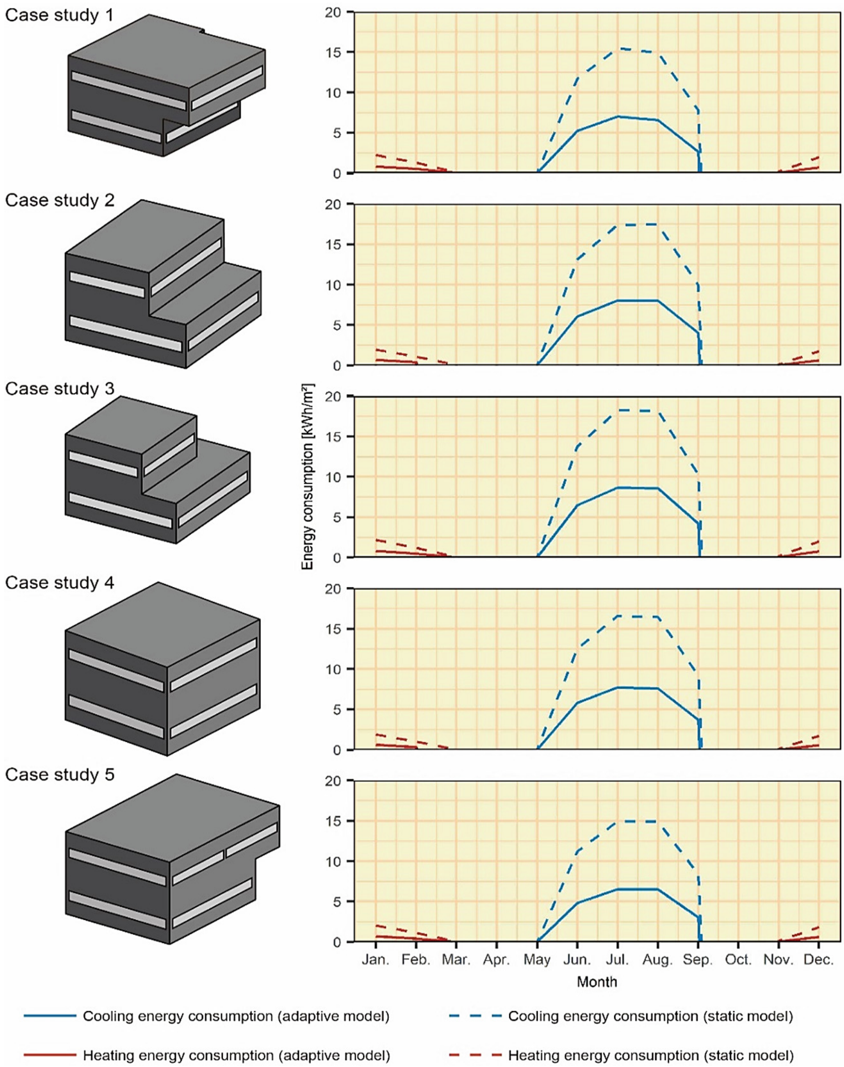

Fig. 3. Monthly energy consumption in different case studies

was greater. It is worth stressing that the climate of Seville corresponds to the Csa class of Köppen-Geiger classification [16]: the Csa class is characterised by mild winters and warm summers. Also, the tendency of energy saving was very similar in all case studies and in the different summer months, with an increase in the percentage deviation lower than 20%.

The reduction of energy consumption became more important when analysing data of annual energy consumption. As can be seen in Fig. 4, the energy consumption of the adaptive thermal comfort model was significantly lower than that of the static model. The energy consumption decreased between 31.85 and 34.61 kWh/m^2 year. Also, the

Table 3. Percentage decrease of energy consumption between the static and adaptive models.

	Energy saving [kWh/m²year]																			
	Case study 1		Case study 2		Case study 3		Case study 4		Case study 5		Case study 6		Case study 7		Case study 8		Case study 9		Case study 10	
Month	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Jan.	1.40	-	1.26	-	1.33	-	1.26	-	1.31	-	1.38	-	1.54	-	1.37	-	1.48	-	1.47	-
Feb.	0.77	-	0.69	-	0.71	-	0.68	-	0.70	-	0.77	-	0.81	-	0.72	-	0.82	-	0.78	-
Mar.	0.10	-	0.04	-	0.05	-	0.02	-	0.05	-	0.11	-	0.10	-	0.07	-	0.13	-	0.09	-
Apr.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jun.	-	6.44	-	7.10	-	7.27	-	6.72	-	6.38	-	7.21	-	7.73	-	7.23	-	6.50	-	7.12
Jul.	-	8.44	-	9.36	-	9.57	-	8.83	-	8.39	-	9.35	-	10.31	-	9.50	-	8.58	-	9.38
Aug.	-	8.34	-	9.41	-	9.59	-	8.84	-	8.42	-	9.43	-	10.24	-	9.45	-	8.51	-	9.22
Sep.	-	5.11	-	5.91	-	6.07	-	5.49	-	5.32	-	6.18	-	6.47	-	5.99	-	5.27	-	5.64
Oct.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nov.	0.15	-	0.08	-	0.11	-	0.08	-	0.11	-	0.15	-	0.18	-	0.13	-	0.21	-	0.16	-
Dec.	1.25	-	1.15	-	1.23	-	1.14	-	1.18	-	1.23	-	1.34	-	1.24	-	1.29	-	1.32	-

	Percentage decrease of energy consumption [%]																			
	Case study 1		Case study 2		Case study 3		Case study 4		Case study 5		Case study 6		Case study 7		Case study 8		Case study 9		Case study 10	
Month	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Jan.	62.83	-	65.12	-	61.13	-	66.97	-	64.56	-	54.91	-	51.65	-	57.83	-	53.93	-	58.37	-
Feb.	59.11	-	64.26	-	59.38	-	67.38	-	62.54	-	52.48	-	49.53	-	56.14	-	50.32	-	55.41	-
Mar.	92.36	-	100.00	-	99.05	-	100.00	-	99.69	-	75.99	-	74.62	-	91.34	-	70.15	-	82.51	-
Apr.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jun.	-	55.15	-	54.05	-	52.91	-	53.56	-	56.96	-	58.20	-	52.98	-	52.73	-	57.10	-	51.74
Jul.	-	54.59	-	53.81	-	52.46	-	53.31	-	56.20	-	57.68	-	53.63	-	52.71	-	56.44	-	51.97
Aug.	-	55.95	-	54.08	-	52.85	-	53.83	-	56.47	-	57.86	-	54.35	-	53.42	-	57.72	-	53.34
Sep.	-	65.73	-	59.61	-	58.96	-	59.72	-	63.48	-	64.20	-	61.10	-	60.30	-	67.78	-	62.21
Oct.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nov.	73.30	-	70.48	-	65.08	-	76.34	-	74.24	-	50.65	-	44.71	-	57.66	-	55.64	-	62.31	-
Dec.	63.30	-	65.56	-	61.69	-	67.57	-	65.36	-	54.30	-	49.42	-	58.00	-	52.43	-	58.17	-

oscillation with the values of annual saving was similar in the different case studies, with a mean value of 34.61 kWh/m^2 year.

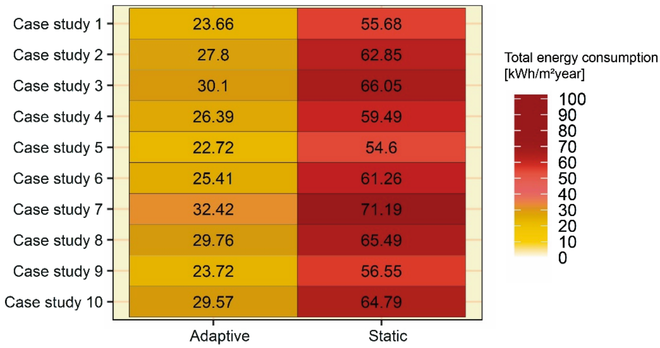

Fig. 4. Heat map with the adaptive and static total energy consumption

The use of the adaptive thermal comfort model therefore implied a great decrease in the main consumption in Seville. The obtaining of considerable reductions in cooling consumption is important to be stressed due to the existing difficulties to reduce this type of energy consumption as, to the contrary of heating, significant reductions by improving the thermal properties of the envelope are not achieved. The use of this type of measure could be an opportunity to improve the energy performance of buildings located in warm regions. In addition, the different geometries of the buildings analysed show the potential of application of this type of energy saving measures in buildings.

Regarding the modification obtained with the new limits of the category III from EN 16798-1:2019, it has been confirmed that the modification carried out in this standard does not imply an important variation with respect to the energy saving achieved with EN 15251:2007 in previous research studies, thus stressing the importance and validity of the results obtained in previous research studies as the modifications of the new standard only affect the lower limit which have a low incidence on the energy consumption in warm regions. However, new research works should be conducted in regions with a colder climate.

4 Conclusions

The results obtained in this study show the potential of using adaptive setpoint temperatures to reduce the energy consumption of buildings in warm climates. By using the new standard on adaptive thermal comfort (EN 17698-1:2019), saving results similar to those obtained in other research studies with the previous standard (EN 15251:2007) were achieved in warm regions (those zones with a greater potential of use of these systems). These results are also the starting point of the need to establish a clear criterion of the maximum limits of acceptability that could be reached inside dwellings with the implementation of adaptive setpoint temperatures. Further studies will therefore analyse the establishment of possible maximum values to be reached inside dwellings. Also, the modification of the lower limit of EN 17698-1:2019 should be studied in other climate zones to determine the degree of improvement in the energy saving achieved in regions with a greater severity in winter.

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