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Extending the use of adaptive thermal comfort to air-conditioning: The case study of a local Japanese comfort model in present and future scenarios

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ABSTRACT

The use of setpoint temperatures based on adaptive thermal comfort models has been identified as an efficient energy saving measure in the latest years. The recent studies applying adaptive setpoint temperatures consider ASHRAE and EN16798-1 international models. However, this study has considered a local Japanese adaptive comfort model instead. Therefore, this study analyses the energy demand resulting from the application of a local Japanese comfort model and compares it with the energy demand resulting from the use of the worldwide ASHRAE Standard 55 adaptive model and other fixed setpoint temperatures. Building energy simulations have been performed considering all different climate zones in the territory of Japan, and also considering full air-conditioning and mixed-mode building operation modes, as well as present and future scenarios under the influence of climate change, namely Representative Concentration Pathways (RCP) 2.6, 4.5 and 8.5 for years 2050 and 2100. Results show that energy savings ranging between 29 and 52% and 33 and 78% could be achieved by using setpoint temperatures based on the Japanese local adaptive comfort model respectively in full air-conditioning mode and mixed-mode. These results were obtained using the adaptive model for free running buildings, therefore assuming high levels of adaptation. In the context of climate change, the total energy demand decreases in cold climates between 14 and 65% and 18 and 91% for full air-conditioning mode and mixed mode respectively, while in warm climates, it increases between 8 and 36% and 17 and 51%, again respectively for full air-conditioning mode and mixed-mode. Therefore, the use of setpoint temperatures based on the Japanese local adaptive comfort model is identified as a very efficient energy saving strategy.

1. Introduction

Building sector is responsible for around 30 % of the energy consumption at a global level [1], thus generating 40 % of greenhouse gas (GHG) emissions. For this reason, the goal is to reduce the GHG emissions in 2050 by at least 80 %. To achieve this, the building sector is required to bluntly reduce GHG emissions (approximately 90 %), among others. These assertive policies time overlap with a pandemic situation and an increase in energy costs. For this reason, managing the energy to guarantee well-being conditions is more and more holistically understood, considering the increment of time people spend at home due to intermittent confinement periods.

From the foundation of the Intergovernmental Panel on Climate Change (IPCC) in 1988, 6 assessment reports [2] have been written and many studies focus on climate change, the increase of GHG emissions, and the shortage of natural resources [3–5]. Energy consumption predictions and users' climate adaptability can be modified because of climate change.

Up to now, the integration of users' climate adaptability into the low energy consumption has been proposed through adaptive comfort models. Such models are included in the standards EN 16798-1:2019 [6] and ASHRAE 55-2020 [7], which consider that users can interact with the environment. Both standards are based on two international projects: Smart Control and Thermal Comfort SCATs (carried out in Europe) and RP-884 (carried out in various world locations). The results obtained by such projects showed the relationship between the indoor operative temperature and the outdoor temperature with respect to users' comfort conditions.

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Field experiments showed that occupants' thermal responses in naturally ventilated spaces partially depend on the external climate and differ from the occupants' thermal responses of buildings with centralized HVAC systems, mainly due to the differences in the thermal experience, the control availability, and changes in occupants' expectations [8].

In recent years specific adaptive thermal comfort models have been developed to (i) avoid the limitations of the international models, (ii) to understand the particularity of each country and (iii) specific living or building use conditions:

(i) The two international adaptive comfort models' limitations are based mainly in the case studies considered. The EN 16798-1:2019 standard, which is the result of the SCATs project, states that the comfort standard is based on a limited data acquisition for outdoor temperatures greater than 25 °C because, among all the countries involved, data with such conditions are only available for two buildings in Greece, and most of the sample belongs to countries with colder climates (e.g., United Kingdom and France). In other words, by using this model for warm climates, the results are limited, and its applicability is reduced, particularly considering the research on the effect of climate change [9,10]. In the case of ASHRAE 55-2020, even though the cases studies database considers worldwide cases, various of them are mixed-mode and centralized HVAC buildings. For this reason, specific cases could vary for the different thresholds considered.

(ii) Various national standards have been developed in recent years, that is the case of ISSO 74 [11,12] from the Netherlands and GB/T50785 [13] from China. The first one in the second version of 2014 [14] is focused on the building indoor spaces with 4 categories of acceptability using both international databases and local studies with different the upper and lower limits. In the case of the Chinese standard, two different models are set according to the cold and warm and mild climate zones. Each model also establishes two different categories and the limits present differences with international standards. Moreover, in China specific models were also developed for specific regions [15].

(iii) The last tendency worldwide is to generate specific studies for different building uses or to understand actual living situations. In this sense, a study was developed in India for office buildings [16] with 2 different models (natural ventilation or mixed-mode) with 3 percentages of acceptability. Other examples are the model developed for social housing of Chile, characterized for low temperatures [17]; an specific adaptive comfort model for the elderly in Shangai [18]; or the two specific models for residential models in Australia [19] and for natural ventilation buildings in Bucharest [20].

Another similar case is the local adaptive comfort model for Japan, developed by Rijal et al [21], which has been used in this paper as the local model for comparison with the international model and setpoint temperatures suggested by the local Japanese Government. This model was developed in order to quantify the seasonal differences in the comfort temperature and to develop a domestic adaptive model for Japanese dwellings, based on a thermal field study conducted for 4 years in the living and bedrooms of dwellings in the Kanto region of Japan, which consists of 36,114 thermal comfort votes from 244 residents of 120 dwellings.

The integration of adaptive comfort models into building significantly influences the energy consumption [22]. In this way, there are some studies where setpoint temperatures were varied to reduce the energy consumption [23,24]. However, most of them use setpoint temperatures based on the Predictive Mean Vote index (PMV). In recent years, a series of research studies have showed how using adaptive setpoint temperatures influence the energy consumption by analysing their advantages and limitations with respect to the models based on the PMV. Some of such studies are as follows: (i) Sánchez-García et al. [25] studied the use of adaptive setpoint temperatures in future climate scenarios with the aim of reducing the energy demand in office buildings. The daily adjustment of setpoint temperatures reduced the demand and the total HVAC consumption between 63 and 52 %, and between 61 and 51 %, respectively, depending on the climate scenario analysed by the authors; (ii) Holmes and Hacker [26] analysed the application of the adaptive thermal comfort approach in various administrative buildings in United Kingdom, both in the current and future scenarios; (iii) Kramer et al. [27] assigned the lower limit of the comfort zone of the model developed by Van der Linden et al. [28] (established in the ISSO 74 standard [11,12]) to the heating setpoint temperature of a museum, thus reducing the energy consumption by 74 %; (iv) Sánchez-Guevara Sánchez et al. [29] applied the adaptive comfort model from ASHRAE 55–2013 through setpoint temperatures which monthly varied, thus reducing the heating energy demand by 20 % and the cooling energy demand by 80 %; and (v) Barbadilla-Martín et al. [30] compared energy demands of a mixed-mode building by using both usual setpoint temperatures and setpoint temperatures based on the neutral temperature of a comfort model previously developed in the city of Seville. Results showed reductions of 27.5 % and 11.4 % in cooling and heating energy consumption, respectively.

At this point, some clarifications need to be done. When de Dear and Brager first published their adaptive comfort regression models in 1998, they used a metric of outdoor climate as the independent variable. They found that although air-conditioned (AC) buildings had little to no adaptation impact, naturally ventilated (NV) buildings yielded a strongly adaptive comfort model. Due to this, de Dear and Brager and later ASHRAE TC 2.1 (in charge of Standard 55) came to the first conclusion in 1998 that adaptive comfort models were only useful in naturally ventilated buildings [8]. Because there were so few mixed-mode (MM) building data in the initial RP-884 database, there was not enough information in the 1998 study to draw a firm conclusion on MM buildings. Nevertheless, using a much larger database, Parkinson et al. reanalyzed the original ASHRAE adaptive models in their 2020 publication [31]. A remarkable and consistent adaptive model fitted remarkably well across all building types - AC, NV, and MM alike - when inside temperature was used as the independent variable rather than external temperature. This prompted to re-evaluate the adaptive comfort models' failures in AC and MM buildings. Only by acknowledging that there is an extraordinarily significant association between interior and exterior climates in NV buildings could the 1998 findings be made to fit with the 2020 reanalysis. As a result, what the 1998 research thought to be an adaptation to the outdoor environment in certain buildings was actually a correlation with the indoor climate, which in turn was connected with the outdoor climate. Therefore, this leads to think it is possible to achieve thermal comfort by using adaptive setpoint temperatures.

Given the potential of adaptive setpoint temperatures as energy saving measures, the studies were the use of adaptive setpoint temperatures were tested against PMV-based setpoint temperatures increased in the recent years. However, to carry out these studies much time was consumed, since the procedure to perform building energy simulations with adaptive setpoint temperatures was manual, which also involved tedious and error-prone tasks. To address this weakness, a computational approach named Adaptive-Comfort-Control-Implementation-Script (ACCIS) [32] was developed, and afterwards nested in a Python package named 'accim' [33], which stands for Adaptive-Comfort-Control-Implemented Model. This tool not only allows to automate this process, but also allows to generate multiple building energy models based on the parameters specified by the user and to perform a number of simulations with no limit.

This paper studies the use of setpoint temperatures based on adaptive thermal comfort models. The novelty resides on the fact that the research is focused to local comfort models instead of the previously applied international comfort models. This study not only considers full-air conditioning building operation mode, but also mixed-mode and analyses the use of natural ventilation, and its performance on present and future scenarios under the influence of climate change. Section 2 presents the methodology developed for this study, including the analysis of the different climate zones in Japan in present and future scenarios, the description of the building case of study, the update of the Python package accim to include the Japanese local adaptive model, and finally the use of accim. Section 3 presents the results and discussion, considering the use of the full-air conditioning and mixed-mode building operation modes. Lastly, Section 4 presents the conclusions.

2. Methodology

2.1. Climate zones in Japan

Japanese territory is divided into 8 different climate zones according to the Japanese Building Technical Code, based on the heating degree-days necessities considering a heating setpoint temperature of 18 °C (Fig. 1). Therefore, to provide an overall view of the potential of using local adaptive setpoint temperatures in Japan's territory, climate data (i.e. EnergyPlus Weather, EPW) for one city located in each climate zone has been used in this study. Wen et al [34] already carried out a study considering the different climate zones in Japan, so for consistency purposes with contextual literature, the same locations have been used in this study.

Also, to find out the potential of local adaptive setpoint temperatures in future scenarios under the influence of climate change, Representative Concentration Pathways scenarios were considered, namely RCP2.6, RCP4.5, RCP8.5 for years 2050 and 2100 (Fig. 2). Climate data for the 7 different setting for each location have been generated with Meteonorm. This software is made up of 8,325 weather stations and allows to obtain the EnergyPlus weather (EPW) files of the locations selected in the climate change scenario.

Considering the different climates in Japan are diverse, this study and the chosen location have allowed to find out the suitability of adaptive local setpoint temperatures to the different climates, and the potential of energy saving. From colder (Asahikawa, climate zone 1) to warmer (Naha, climate zone 8) the yearly average outdoor dry-bulb air temperature ranges from 7.1 to 23.6 °C (Fig. 1, Table 1). Also, climate change has a slightly different impact on each location. Depending on the RCP scenario and year, the increment in the yearly average outdoor dry-bulb air temperature ranges from 1.48 to 6.12 °C in Asahikawa, however it ranges from 0.67 to 3.17 °C in Naha, with a roughly 3 °C difference in RCP8.5–2100 scenario (Fig. 1, Table 1).

2.2. Case study

As in many other developed countries, after the Second War Japan initiated a public policy oriented towards the massive construction of public, affordable housing complexes for its population. A recent report from the Ministry of Land, Infrastructure, Transport, and Tourism (MILT) offers an overview of the Japanese public housing stock [35]. The number of built units was not very representative until 1965, with less than 20,000 houses a year. From then on, a construction boom started along with the rapid economic development that Japan experienced during the 1960s and the 1970s; the number of houses built in one year peaked at around 72,000 in 1971, and then started a slow decline until around the mid-nineties, when the number of units was around

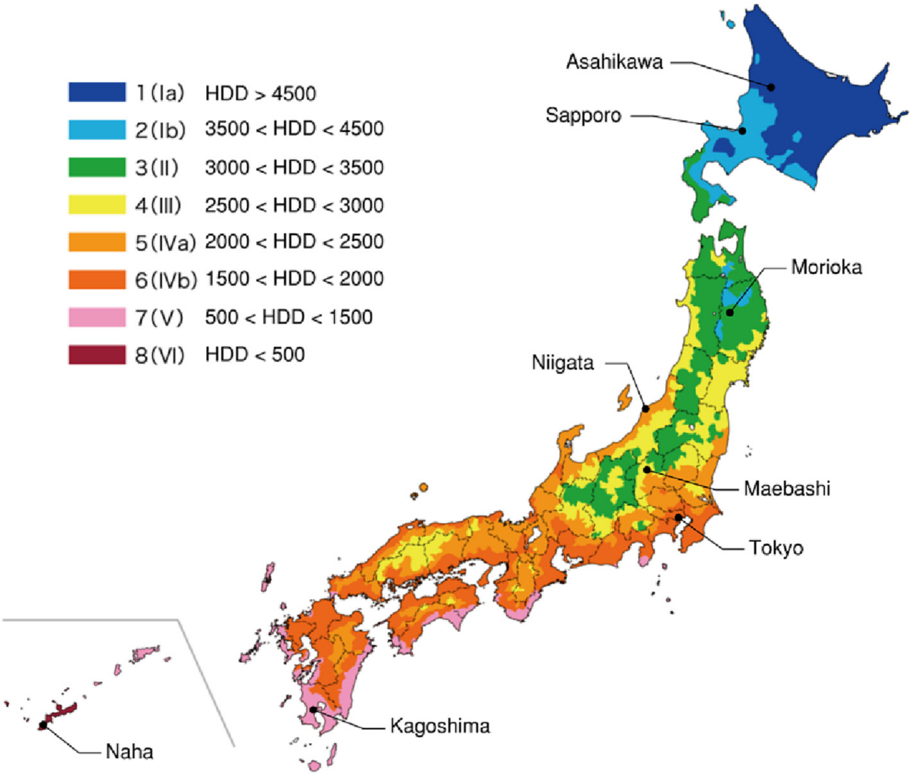

Fig. 1. Climate zones according to Japanese Building Technical Code based on the heating degree-days thresholds.

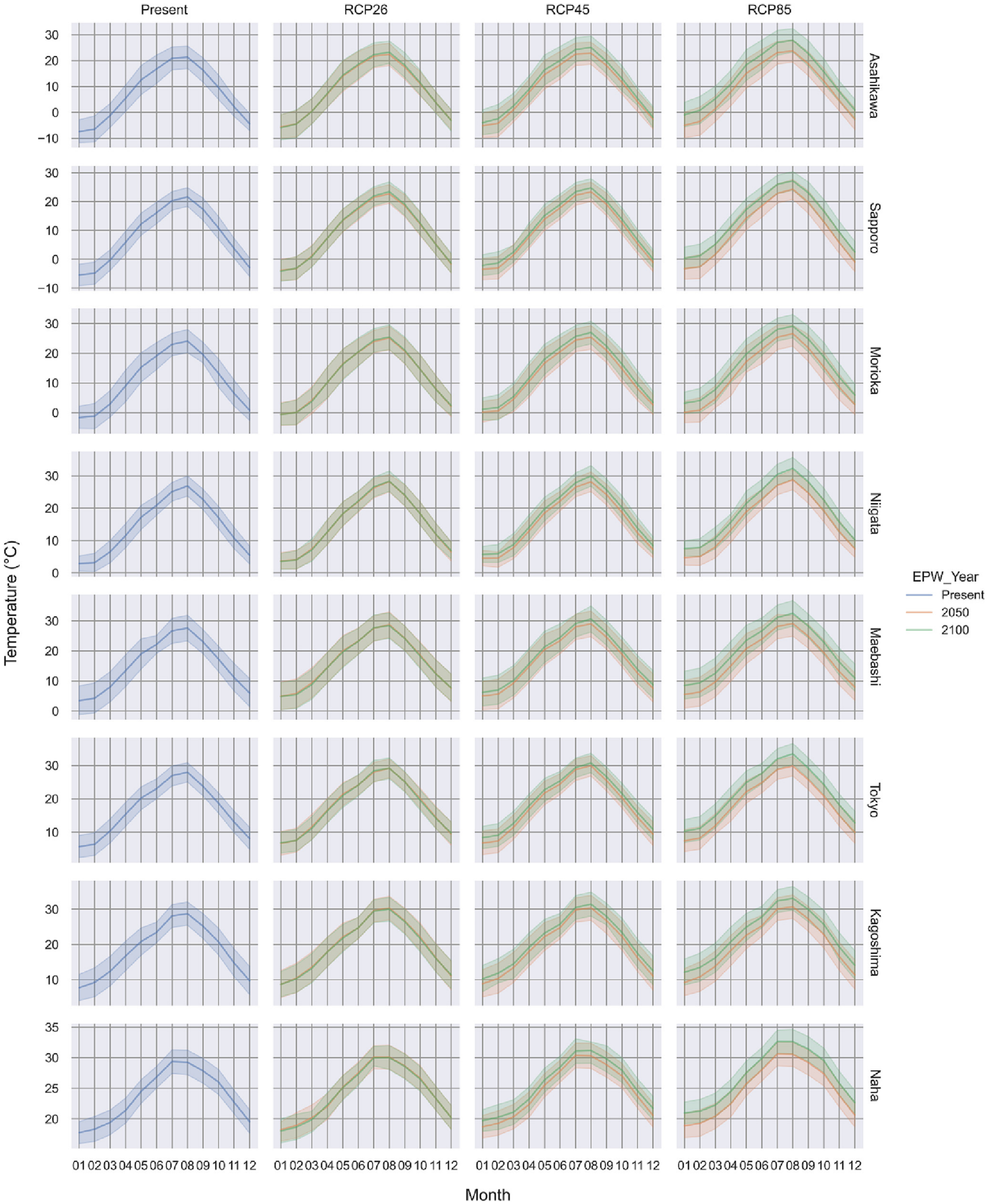

Fig. 2. Outdoor dry-bulb temperature range in the different locations for every RCP scenario and year.

40,000. From that point, the number of public housing projects continued to decrease; the latest data from 2016 indicates that in 2014 no more than 10,000 new units were built. The report also highlights that, as per 2016, 61 % of the public housing stock (around 1.3 million units) were 30 years old or older, and also gives an overview of the social profile of its residents. 59.8 % of them are 60 years old or older, and the monthly income of 79.8 % of the residents is below 104,000 yen (around US $ 900).

Table 1
Basic information of the selected locations.

City	Climate Zone (Koppen-Geiger)	Scenario-Year	Mean Outdoor Dry-bulb Temperature (°C)													
			Months												Year	Increment from present
			1	2	3	4	5	6	7	8	9	10	11	12		
Asahikawa	1 (Dfb)	Present	-7.7	-6.7	-1.3	5.5	12.6	16.9	21.0	21.4	16.3	9.4	2.1	-4.6	7.1	-
		RCP26-2050	-5.9	-4.6	0.4	7.1	14.2	18.3	21.9	22.4	17.5	10.9	3.7	-3.3	8.6	1.48
		RCP26-2100	-6.3	-4.6	0.2	7.4	14.5	18.8	22.4	23.2	18.2	11.3	3.6	-3.3	8.8	1.72
		RCP45-2050	-5.4	-4.4	0.9	7.8	14.8	18.6	22.5	22.9	18.1	11.5	4.0	-2.7	9.0	1.97
		RCP45-2100	-4.3	-2.6	2.4	9.0	16.5	20.2	24.4	25.1	19.6	12.9	5.3	-2.0	10.5	3.47
		RCP85-2050	-5.4	-3.7	1.4	8.0	15.3	19.3	23.2	23.8	18.8	12.0	4.5	-2.6	9.5	2.46
		RCP85-2100	-1.2	0.6	5.2	11.0	18.5	22.6	27.1	27.8	22.6	15.5	7.9	0.8	13.2	6.12
Sapporo	2 (Dfa)	Present	-5.6	-5.0	-0.3	6.0	12.3	16.3	20.4	21.7	17.3	10.7	3.6	-3.0	7.9	-
		RCP26-2050	-4.1	-3.4	1.1	7.4	13.6	17.7	21.5	22.8	18.6	12.1	5.1	-1.8	9.2	1.35
		RCP26-2100	-4.3	-3.3	0.8	7.4	13.7	18.0	22.1	23.5	19.1	12.3	5.0	-1.5	9.4	1.53
		RCP45-2050	-3.6	-3.2	1.4	7.8	13.9	17.9	22.2	23.4	19.0	12.5	5.3	-1.2	9.6	1.76
		RCP45-2100	-2.3	-1.4	2.5	8.8	15.2	19.1	23.5	24.8	20.2	13.8	6.6	-0.1	10.9	3.02
		RCP85-2050	-3.5	-2.6	1.7	7.9	14.3	18.6	22.9	24.3	19.7	13.0	5.7	-1.1	10.1	2.20
		RCP85-2100	0.1	1.0	5.2	11.2	17.4	21.7	26.1	27.3	23.1	16.6	9.4	2.4	13.4	5.57
Morioka	3 (Dfa)	Present	-1.8	-1.3	2.9	9.1	15.4	19.2	23.0	24.1	19.5	13.1	6.4	0.7	10.9	-
		RCP26-2050	-0.7	-0.1	4.1	10.2	16.5	20.4	24.0	25.1	20.7	14.5	7.9	1.9	12.0	1.19
		RCP26-2100	-0.8	-0.1	3.7	10.2	16.4	20.5	24.4	25.5	21.1	14.5	7.8	2.2	12.1	1.26
		RCP45-2050	0.1	0.4	4.5	10.5	16.8	20.6	24.4	25.4	21.0	14.6	7.9	2.5	12.4	1.54
		RCP45-2100	1.0	1.6	5.4	11.7	18.1	22.0	25.8	27.1	22.4	16.2	9.5	3.3	13.7	2.81
		RCP85-2050	0.0	0.7	4.6	10.8	17.3	21.4	25.5	26.7	21.8	15.2	8.4	2.6	12.9	2.06
		RCP85-2100	3.0	3.9	7.8	13.6	19.9	24.1	28.1	29.2	24.8	18.7	11.8	5.8	15.9	5.03
Niigata	4 (Dfa)	Present	2.8	3.1	6.4	11.6	17.3	21.0	25.2	26.9	22.7	17.0	10.7	5.5	14.2	-
		RCP26-2050	3.6	4.0	7.3	12.6	18.4	22.2	26.4	28.3	23.9	18.1	11.9	6.4	15.2	1.06
		RCP26-2100	3.6	3.9	7.1	12.7	18.3	22.3	26.7	28.4	24.0	18.1	11.9	6.7	15.3	1.13
		RCP45-2050	4.3	4.4	7.8	13.0	18.6	22.3	26.6	28.2	24.2	18.7	12.3	7.1	15.6	1.45
		RCP45-2100	5.6	5.9	8.7	14.1	19.8	23.6	28.0	30.0	25.7	20.1	13.8	8.3	17.0	2.79
		RCP85-2050	4.6	4.9	8.0	13.2	19.0	22.9	27.1	28.8	24.7	19.1	12.7	7.4	16.0	1.86
		RCP85-2100	7.5	7.7	10.7	15.7	21.6	25.7	30.5	32.3	28.1	22.4	15.6	10.2	19.0	4.82
Maebashi	5 (Cfa)	Present	3.2	4.0	7.9	13.3	19.0	22.2	26.7	27.6	22.9	17.1	11.0	5.8	15.1	-
		RCP26-2050	4.6	5.6	9.2	14.4	20.1	23.3	27.6	28.8	24.2	18.4	12.3	7.3	16.3	1.25
		RCP26-2100	4.5	5.3	8.7	14.4	19.7	23.2	27.7	28.4	24.1	18.0	12.2	7.4	16.1	1.07
		RCP45-2050	4.7	5.4	9.1	14.7	20.4	23.4	28.1	29.0	24.4	18.7	12.4	7.3	16.5	1.42
		RCP45-2100	6.0	6.8	10.0	15.7	21.3	24.5	29.2	30.6	25.9	19.9	13.7	8.5	17.7	2.60
		RCP85-2050	5.2	6.1	9.5	15.0	20.8	23.9	28.2	29.1	24.8	19.3	13.0	7.8	16.9	1.83
		RCP85-2100	8.2	9.2	12.5	17.9	23.5	26.7	31.2	32.5	28.2	22.7	16.1	10.7	19.9	4.89
Tokyo	6 (Cfa)	Present	5.4	6.2	10.3	15.4	20.3	23.1	27.1	28.0	23.7	18.6	13.0	7.9	16.6	-
		RCP26-2050	6.4	7.4	11.6	16.6	21.5	24.2	28.1	29.2	25.1	19.9	14.3	9.3	17.8	1.22
		RCP26-2100	6.7	7.4	11.1	16.3	21.0	24.2	28.5	29.2	25.0	19.4	14.1	9.5	17.7	1.13
		RCP45-2050	6.6	7.2	11.4	16.8	21.8	24.5	28.9	29.9	25.4	20.2	14.4	9.2	18.0	1.43
		RCP45-2100	8.2	8.9	12.6	17.9	22.8	25.5	29.5	30.8	26.7	21.5	15.8	10.7	19.2	2.65
		RCP85-2050	7.2	8.1	11.9	17.0	22.2	24.9	28.9	29.8	25.8	20.8	14.9	9.8	18.4	1.85
		RCP85-2100	10.1	11.0	14.8	19.9	24.9	27.8	32.1	33.5	29.2	24.2	18.1	12.7	21.5	4.93
Kagoshima	7 (Cfa)	Present	7.5	9.1	12.2	16.7	20.8	23.4	28.1	28.7	25.1	20.6	14.7	9.6	18.0	-
		RCP26-2050	8.5	10.3	13.5	17.9	22.1	24.8	29.7	30.3	26.6	21.9	16.1	10.9	19.4	1.32
		RCP26-2100	8.5	10.0	13.1	17.8	21.8	24.8	29.5	30.0	26.4	21.5	15.9	11.1	19.2	1.14
		RCP45-2050	8.7	10.1	13.4	17.9	22.1	24.8	29.8	30.4	26.7	22.1	16.0	10.9	19.4	1.37
		RCP45-2100	10.1	11.6	14.4	19.1	23.2	25.8	30.5	31.4	27.8	23.3	17.3	12.3	20.6	2.53
		RCP85-2050	9.0	10.6	13.7	18.3	22.6	25.3	30.1	30.6	27.1	22.7	16.5	11.2	19.8	1.77
		RCP85-2100	11.9	13.3	16.1	20.7	24.9	27.7	32.3	33.1	29.8	25.6	19.1	13.9	22.4	4.33
Naha	8 (Cfa)	Present	17.7	18.2	19.4	21.4	24.5	26.9	29.4	29.3	27.8	26.0	22.7	19.5	23.6	-
		RCP26-2050	18.2	18.9	20.2	22.0	25.2	27.6	30.1	30.1	28.6	26.6	23.3	20.2	24.2	0.67
		RCP26-2100	18.0	18.6	19.8	22.3	25.1	27.4	30.0	30.0	28.6	26.4	23.3	20.1	24.1	0.56
		RCP45-2050	18.6	19.2	20.3	22.4	25.5	27.8	30.4	30.3	28.8	27.0	23.6	20.5	24.5	0.97
		RCP45-2100	19.6	20.2	21.1	23.3	26.4	28.5	31.1	31.2	29.8	27.9	24.5	21.6	25.4	1.86
		RCP85-2050	18.8	19.2	20.4	22.4	25.8	28.0	30.6	30.5	29.2	27.4	23.8	20.6	24.7	1.15
		RCP85-2100	20.9	21.2	22.2	24.5	27.6	29.9	32.6	32.6	31.4	29.5	25.7	22.6	26.7	3.17

This paper considers one of the most popular models of Japanese public housing: The 51C. It was named after the year when it was firstly developed by a group of Japanese researchers on public housing (1951) [36]. It consists of a 2DK (Dining-Kitchen) apartment following an open-plan concept (Fig. 3). The entry space gives access to a dining-kitchen area that directly connects with the two

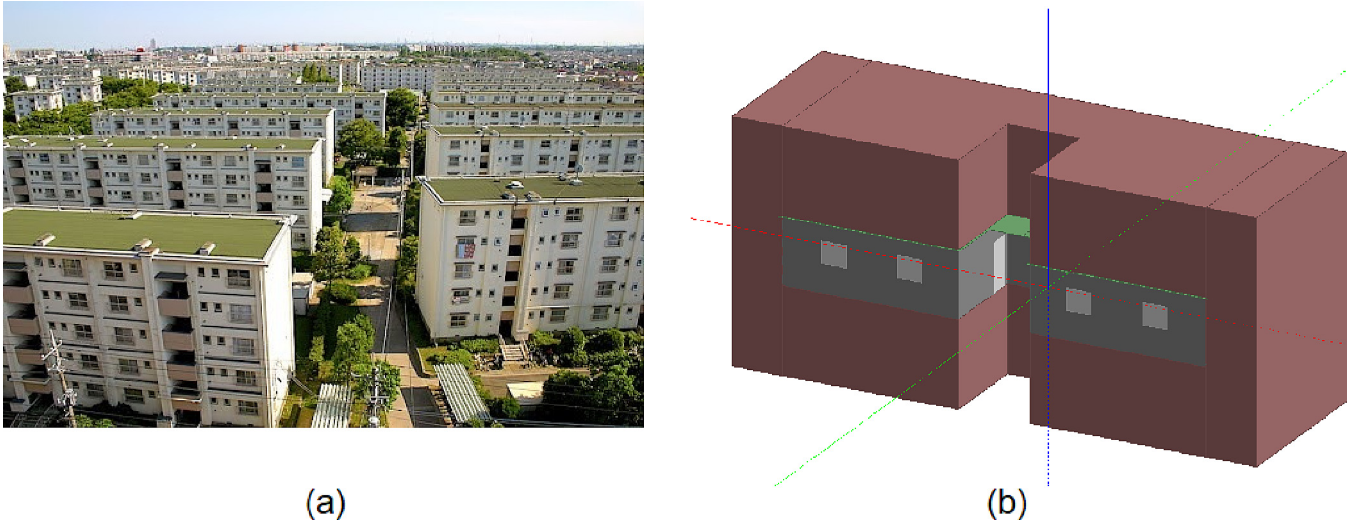

Fig. 3. Original case study (a); building energy model (b).

bedrooms, whose area is measured in tatami mats. The main bedroom has 6 tatami mats (circa 10 sqm), and the smallest one 5 tatami (circa 8 sqm). Those bedrooms were not intended to have beds but sleeping mats (futons) that would be folded and stored inside the closet during daytime, being laid out on the tatami before sleeping. In such way, the two bedrooms are flexible spaces that can be used for different purposes. The toilet is separated from the bathroom area, which features a small sink and a Japanese bathtub. All rooms except for the bathroom and the toilet communicate with each other through sliding doors. The public housing complexes usually occupy large plots; therefore, each block is separated from its neighbors, and surrounded by communal green areas. The apartments are organized into long 4-story blocks, where one staircase gives access to two units in each floor. Each unit has a long balcony, usually facing South, and windows facing North, fostering in this way crossed ventilation in all rooms.

This prototype had a significant impact on subsequent developments, becoming a model for many public housing projects afterwards. Japanese authors have argued that the "*standard planning type called 51C for public housing has long been regarded as the turning point of the prevailing style of dining-kitchen in Japanese housing*" [37]. Al tough the typology evolved through time, its basic design featured in terms of distribution and block arrangement have remained almost intact. Open-plan based on the LDK as the central space, cross-ventilation, and an arrangement in long blocks with staircases serving two symmetrical units on each side.

Regarding the characteristics of the envelope, the façade is characterized by a design of painted concrete wall with internal insulation and plywood board with painted paper internal finish (1.0267 W/m^{2}K), while the roof is composed by concrete floor tiles and a concrete slab with rigid insulation (1.2238 W/m^{2}K). The windows consist of a 3 mm single glazing with wooden frame. Detailed information is provided in Table 2. All these designs have been typically used in social building apartments, and therefore have been included in the building energy model developed for this study.

The current Japanese Building Technical Code states that different building characteristics must be applied depending on the climate zone (e.g. U-value). However, in this study a typical and representative dwelling has been chosen in order to maximize the impact of the study, and therefore it has been modelled following the Japanese regulations applicable to that period (1983). In that regulations, differences in building characteristics due to the climate zones were not considered yet, so the same building characteristics have been used for the whole territory.

The usage profile for the building case of study is provided in Table 3. This profile is representative of the use of residential buildings and considers three types of loads: occupancy, equipment and lighting. Occupancy loads varied according to the type of day (weekdays or weekend), and the load profiles of equipment and lighting systems were the same. The original case of study did not account for any HVAC system. However, so that energy rates could be calculated, a VRF system was considered in the building energy model, with an Energy Efficiency Ratio (EER) value of 2.0 and a Coefficient of Performance (COP) value of 2.1.

This background information shapes the scope of our research, which targets a prototype of Japanese social housing representative of an aged residential stock, with elder dwellers living on a meagre income.

2.3. Inclusion of Japanese local adaptive model in accim

Up to now, only the Spanish standard for energy calculations included in the Building Technical Code (CTE by its initials in Spanish) and 2 international thermal comfort standards were included in the Python package accim: EN 16798–1 and ASHRAE 55. However, in order to identify the variations in energy demand, a Japanese local adaptive model has been included. This model,

Table 2
Characteristics of the building case of study.

Element	Layers (outside to inside)	U-value (W/m^{2}K)
Envelope	Coat of paint 15 cm Concrete structural wall 3 cm Rigid insulation (0.03 W/mK) Plywood board Painted paper	1.0267
Roof	5 cm Concrete floor tiles 3 cm Rigid insulation Waterproofing sheet 15 cm Structural concrete slab	1.2238
Internal partitions	Painted paper 2 cm Plywood board 6 cm Timber studs substructure 2 cm Plywood board Painted paper	1.4733
Ground floor slab	15 cm Structural concrete slab Vinyl flooring	0.5699
Windows	3 mm Clear Single glazing Painted wooden frame	5.8940 3.6330

Table 3
Use profile of rooms at the building case of study.

Type of load	Days	Hours and load (W/m^2)					
		0:00–6:59	07:00–14:59	15:00–17:59	18:00–18:59	19:00–22:59	23:00–23:59
Occupancy (sensible)	Mon., Tue., Wed., Thu., Fri.	2.15	0.54	1.08	1.08	1.08	2.15
	Sat., Sun.	2.15	2.15	2.15	2.15	2.15	2.15
Occupancy (latent)	Mon., Tue., Wed., Thu., Fri.	1.36	0.34	0.68	0.68	0.68	1.36
	Sat., Sun.	1.36	1.36	1.36	1.36	1.36	1.36
Lighting	Week	0.44	1.32	1.32	2.2	4.4	2.2
Equipment	Week	0.44	1.32	1.32	2.2	4.4	2.2

developed by Rijal et al. [21], has been chosen based on its high reliability, considering the large number of thermal comfort votes collected.

Adaptive comfort models are generally built based on a weighted mean outdoor temperature, whose name changes depending on the adaptive standard. In this case, since ASHRAE 55 is considered as the baseline for the comparison with the local adaptive model, Prevailing Mean Outdoor Temperature (PMOT) will be used, in accordance with ASHRAE 55 framework (Eq. (1)). Comfort temperature equation is obtained by means of linear regression (Fig. 4), and it takes PMOT as an input (Eq. (2))

$$PMOT = (T_{ext,d-1} + 0.8T_{ext,d-2} + 0.6T_{ext,d-3} + 0.5T_{ext,d-4} + 0.4T_{ext,d-5} + 0.3T_{ext,d-6} + 0.2T_{ext,d-7})/3.8\ [^\circ\mathrm{C}] \quad (1)$$

$$\mathit{Comfort\ temperature} = 0.48 \cdot \mathrm{PMOT} + 14.4\ [^\circ\mathrm{C}] \quad (2)$$

where $T_{ext,d-1}$ is the average temperature of the previous day to the day in question, $T_{ext,d-2}$ the average temperature of the day before, and so on.

At this point, some clarifications need to be done. Until recently, adaptive comfort models were considered to be applicable only to naturally ventilated spaces. However, as previously explained, a recent study [31] has found out that occupants tend to adapt to the indoor environment, whether naturally ventilated or air-conditioned. Therefore, this study is based on the assumption that occupants will adapt to the air-conditioned space as if it was naturally ventilated, although it is a topic that certainly needs further investigation, and therefore it is stated as a limitation.

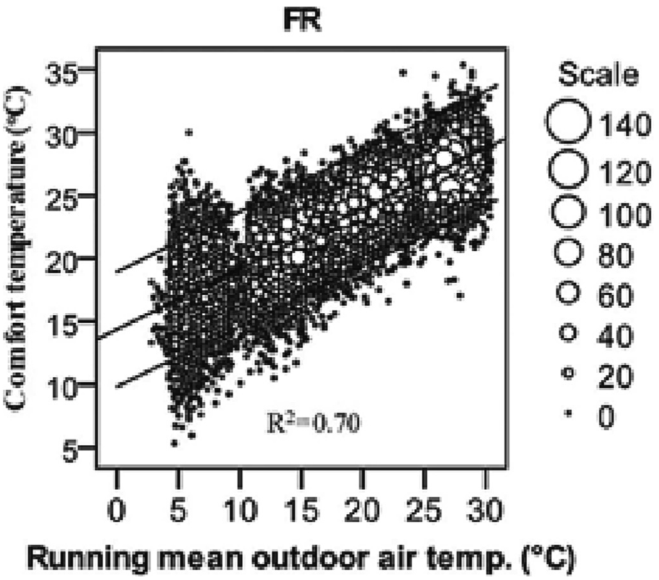

Fig. 4. Linear regression of the Japanese local adaptive comfort model by Rijal et al. [21] for free-running mode.

Since some information necessary for the implementation was not provided in the research article, some assumptions had to be done: applicability limits have been considered 5 °C and 30 °C for both upper and lower comfort limits, and offsets from comfort temperature for comfort limits have been considered ±3.5 °C and ±2.5 °C for 80 % and 90 % acceptability levels for consistency purposes, since the international adaptive comfort model used as a baseline for comparison is ASHRAE 55. Considering these assumptions, the equations for upper and lower comfort limits are (Eqs. (3)–(6)).

$$\mathit{Upper\ limit}\,(80\%\ \mathit{acceptability}) = 0.48 \cdot \mathrm{PMOT} + 14.4 + 3.5\ [^\circ\mathrm{C}] \quad (5\,^\circ\mathrm{C} \leqslant \mathit{PMOT} \leqslant 30\,^\circ\mathrm{C}) \quad (3)$$

$$\mathit{Lower\ limit}\,(80\%\ \mathit{acceptability}) = 0.48 \cdot \mathrm{PMOT} + 14.4 - 3.5\ [^\circ\mathrm{C}] \quad (5\,^\circ\mathrm{C} \leqslant \mathit{PMOT} \leqslant 30\,^\circ\mathrm{C}) \quad (4)$$

$$\mathit{Upper\ limit}\,(90\%\ \mathit{acceptability}) = 0.48 \cdot \mathrm{PMOT} + 14.4 + 2.5\,[^\circ\mathrm{C}] \quad (5\,^\circ\mathrm{C} \leqslant \mathit{PMOT} \leqslant 30\,^\circ\mathrm{C}) \quad (5)$$

$$\mathit{Lower\ limit}\,(90\%\ \mathit{acceptability}) = 0.48 \cdot \mathrm{PMOT} + 14.4 - 2.5\ [^\circ\mathrm{C}] \quad (5\,^\circ\mathrm{C} \leqslant \mathit{PMOT} \leqslant 30\,^\circ\mathrm{C}) \quad (6)$$

For consistency with the current development of accim and the flexible and highly custom setpoint temperatures it can apply, the different options available are briefly explained below, and gathered in Table 4, although not all of them have been used in this study. For clarity purposes, the comfort models and settings actually used in the study have been collected in the later Table 5. In the implementation of adaptive setpoint temperatures process carried out by accim (version 0.6.0), these are applied by an EnergyManagementSystem:Program object called 'SetAST' (which means Set Adaptive Setpoint Temperatures) based on the different parameters specified by the user: 'ComfStand', 'CAT' and 'ComfMod'. These parameters have been previously studied in [38–40]. Table 4 provides all values related to the Japanese local adaptive model. CAT refers to the acceptability levels (i.e. occupant expectations), and overrides the width of the comfort zone (increases and decreases 1 °C the cooling and heating setpoint temperature respectively, therefore changing from 2.5 to 3.5 and −2.5 to −3.5 for cooling and heating setpoint temperatures respectively), while ComfMod refers to the comfort mode (determines the behaviour of the setpoint temperatures when adaptive applicability limits are not met, i.e PMOT < 5 °C or 30 °C < PMOT). When ComfMod equals 0, static or PMV-based setpoint temperatures are used. In this case, the static model is based on setpoint temperatures suggested by the Japanese Local Government. In case of the heating setpoint temperature, 18 °C is the baseline used for calculation of heating

Table 4
Setpoint temperatures values as a function of parameters ComfStand, CAT and ComfMod, and applicability limits.

ComfStand	CAT	ComfMod	Cooling setpoint temperature			Heating setpoint temperature		
			PMOT < 5 °C	5 °C < PMOT < 30 °C	30 °C < PMOT	PMOT < 5 °C	5 °C < PMOT < 30 °C	30 °C < PMOT
3	90	0	27			19		
		1	27	PMOT*0.48 + 14.4 + 2.5	27	19	PMOT*0.48 + 14.4–2.5	19
		2	24	PMOT*0.48 + 14.4 + 2.5	26	20	PMOT*0.48 + 14.4–2.5	23
		3	5*0.48 + 14.4 + 2.5	PMOT*0.48 + 14.4 + 2.5	30*0.48 + 14.4 + 2.5	5*0.48 + 14.4–2.5	PMOT*0.48 + 14.4–2.5	30*0.48 + 14.4–2.5
	80	0	28			18		
		1	28	PMOT*0.48 + 14.4 + 3.5	28	18	PMOT*0.48 + 14.4–3.5	18
		2	25	PMOT*0.48 + 14.4 + 3.5	27	19	PMOT*0.48 + 14.4–3.5	22
		3	5*0.48 + 14.4 + 3.5	PMOT*0.48 + 14.4 + 3.5	30*0.48 + 14.4 + 3.5	5*0.48 + 14.4–3.5	PMOT*0.48 + 14.4–3.5	30*0.48 + 14.4–3.5

PMOT: Prevailing mean outdoor temperature.

Table 5
Comfort models considered in the study.

ComfStand	CAT	ComfMod	Cooling setpoint temperature (°C)			Heating setpoint temperature (°C)		
			PMOT < ACSTall	ACSTall < PMOT < ACSTaul	ACSTaul < PMOT	PMOT < AHSTall	AHSTall < PMOT < AHSTaul	AHSTaul < PMOT
2	80	3	10*0.31 + 17.8 + 3.5	PMOT*0.31 + 17.8 + 3.5	33.5*0.31 + 17.8 + 3.5	10*0.31 + 17.8–3.5	PMOT*0.31 + 17.8–3.5	33.5*0.31 + 17.8–3.5
3	80	0	28			18		
		3	5*0.48 + 14.4 + 3.5	PMOT*0.48 + 14.4 + 3.5	30*0.48 + 14.4 + 3.5	5*0.48 + 14.4–3.5	PMOT*0.48 + 14.4–3.5	30*0.48 + 14.4–3.5

PMOT: Prevailing mean outdoor temperature;
ACSTall: Adaptive Cooling Setpoint Temperature applicability lower limit; ACSTaul: Adaptive Cooling Setpoint Temperature applicability upper limit;
AHSTall: Adaptive Heating Setpoint Temperature applicability lower limit; AHSTaul: Adaptive Heating Setpoint Temperature applicability upper limit;

degree-days in the Japanese Building Technical Code, while in case of the cooling setpoint temperature, 28 °C is the temperature that the Japanese Government suggested to use in summer after the Fukushima nuclear plant incident with energy-saving purposes, considering that office workers would be allowed to wear casual clothes instead of suit and tie (COOL BIZ campaign [41]). Therefore, 28 °C has been considered the cooling setpoint temperature not only because occupants are considered to wear casual clothes, but also for consistency purposes with other relevant research articles [42]. Else, when ComfMod is different to 0, the selected adaptive standard (determined by the parameter ComfStand) is applied when applicability limits are met, otherwise static setpoints are applied. What changes between ComfMod = 1, ComfMod = 2 and ComfMod = 3 is the static model applied:

(i) in case of 1, static model is the previously explained based on the heating degree-days setpoint and the COOL BIZ campaign.
(ii) in case of 2, static model is based on setpoint temperatures based on the static model of ISO 7730 [43].
(iii) in case of 3, static model is based on the horizontal extension of the adaptive comfort limits (which is the same equation, but with 5 and 30 instead of PMOT).

This tool has been designed aiming to provide thermal comfort for all hours throughout the year. Therefore, at each hour of the year, there must be a heating and a cooling setpoint temperature. That means, there must be a cooling setpoint temperature in winter or heating season and a heating setpoint temperature in summer or cooling season. For instance, it is very unlikely that indoor temperature rises above 27 or 28 °C when PMOT falls below 5 °C, or falls below 18 or 19 °C when PMOT rises above 30 °C, but setpoint temperatures need to be set to make sure all hours are comfortable.

2.4. Use of accim

Following the principles and criteria established in accim, the tool has been updated maintaining its ease of use. Once Python is installed, the accim Python package can be installed typing 'pip install accim'. Then, given there is at least one IDF file (which is the EnergyPlus building energy model itself) in some folder, the user needs to open the command prompt in that folder and execute Python. Finally, it just takes 2 lines of code:

```
from accim.sim import accis
accis.addAccis()
```

Afterwards, the tool will ask the user some information related to the settings for the output IDF files the tool will generate. It is also possible to specify the desired parameters when calling the function, as carefully explained in the available documentation [44]. For example, the code for accim version 0.6.0 used for this study has been the following:

```
from accim.sim import accis
accis.addAccis(
    ScriptType='vrf',
    SupplyAirTempInputMethod='supply air temperature',
    TempCtrl='temp',
    Output_keep_existing=False,
    Output_type='standard',
    Output_freqs=['hourly'],
    EnergyPlus_version='9.6',
    ComfStand=[2, 3],
    CAT=[80],
    ComfMod=[0, 3],
    HVACmode=[0, 2],
    VentCtrl=[0],
    VSToffset=[0],
    MinOToffset=[50],
    MaxWindSpeed=[50],
    ASTtol_start=0.1,
```

2.5. Comfort models considered

In order to evaluate the energy performance of the Japanese local adaptive comfort model in full air-conditioning and mixed-mode operations, 2 different reference comfort models have been selected for comparison: ASHRAE 55, since it is the only world—wide adaptive comfort model, and the COOL BIZ's setpoint temperatures, in order to provide a reference of static setpoint temperatures consistent to the culture of Japan. The values or equations of the setpoint temperatures for each model used in this study are collected in Table 5. Therefore, consistently with the explanation of the arguments ComfStand, CAT and ComfMod above, in this table ComfStand = 2 and ComfMod = 3 refers to ASHRAE 55 adaptive model, while ComfStand = 3 and ComfMod = 0 and 3 refers respectively to the Japanese model using static setpoint (i.e. COOL BIZ) and adaptive setpoint temperatures.

The Japanese local comfort model used in this paper has been developed based on thermal comfort surveys in the Kanto region of Japan (Kanagawa, Tokyo, Saitama and Chiba), which is regarded in the climate zones map (Fig. 1) as zones 5 and 6. However, in the absence of a comfort model for Japanese colder climate zones, adaptive setpoint temperatures based on this local model have been used for those colder zones, such as the cities of Asahikawa and Sapporo. This is presented as a limitation of the study, due to the fact that using a local comfort model carried out for a temperate climate in a colder climate is expected to introduce certain inaccuracies.

3. Results and discussion

The energy performance of the setpoint temperatures based on the Japanese adaptive local comfort model has been analysed at the first and second sub-sections considering two different building operations: full air-conditioning mode, where no ventilation is allowed, and mixed-mode, where natural ventilation is prioritised against the use of the HVAC system when outdoor conditions are acceptable, otherwise air-conditioning is used and windows are closed. Also, the impact of climate change on energy demand and ventilation is analysed in the third sub-section. At this point, it must be clarified that all simulation results based on the use of adaptive setpoint temperatures have been obtained using the adaptive models for free-running buildings (that is, using comfort limits as setpoint temperatures), therefore assuming high levels of adaptation.

3.1. Full air-conditioning energy performance

The energy performance of the setpoint temperatures based on the Japanese adaptive local comfort model (named JPN_Adap_AC) has been analysed considering the full air-conditioning building operation mode, and it has been compared to the energy performance of the adaptive model of the ASHRAE 55 (named ASH_Adap_AC) and the static setpoint temperatures from the COOL BIZ campaign (named JPN_Stat_AC).

Table 6
Cooling, heating and total energy demand of JPN_Adap_AC compared to ASH_Adap_AC and JPN_Stat_AC.

Operation mode	Comfort model	Climate zone								
		Asahikawa	Sapporo	Morioka	Niigata	Maebashi	Tokyo	Kagoshima	Naha	Average
Cooling Energy Demand (kWh/m2)	ASH_Adap_AC	96	96	153	215	243	264	319	511	237
	JPN_Stat_AC	82	79	145	229	265	295	357	605	257
	JPN_Adap_AC	58	59	92	127	148	155	187	290	140
	1-(JPN_Adap_AC/ASH_Adap_AC)	40%	38%	39%	41%	39%	41%	41%	43%	40%
	ASH_Adap_AC - JPN_Adap_AC	38	37	60	88	95	109	132	221	98
	1-(JPN_Adap_AC/JPN_Stat_AC)	29%	25%	36%	45%	44%	47%	48%	52%	41%
	JPN_Stat_AC - JPN_Adap_AC	24	20	53	102	116	140	171	315	118
Heating Energy Demand (kWh/m2)	ASH_Adap_AC	944	790	500	258	177	88	47	0	351
	JPN_Stat_AC	985	824	529	277	194	100	52	0	370
	JPN_Adap_AC	685	562	318	143	98	38	32	0	235
	1-(JPN_Adap_AC/ASH_Adap_AC)	27%	29%	36%	44%	45%	57%	32%	0	39%
	ASH_Adap_AC - JPN_Adap_AC	259	228	182	114	80	50	15	0	116
	1-(JPN_Adap_AC/JPN_Stat_AC)	30%	32%	40%	48%	50%	62%	39%	0	43%
	JPN_Stat_AC - JPN_Adap_AC	300	262	211	133	96	62	20	0	136
Total Energy Demand (kWh/m2)	ASH_Adap_AC	1040	886	653	473	420	352	365	511	588
	JPN_Stat_AC	1067	903	674	505	458	395	410	605	627
	JPN_Adap_AC	743	621	411	270	246	193	219	290	374
	1-(JPN_Adap_AC/ASH_Adap_AC)	29%	30%	37%	43%	42%	45%	40%	43%	39%
	ASH_Adap_AC - JPN_Adap_AC	297	265	242	203	175	160	147	221	214
	1-(JPN_Adap_AC/JPN_Stat_AC)	30%	31%	39%	47%	46%	51%	47%	52%	43%
	JPN_Stat_AC - JPN_Adap_AC	324	282	264	235	213	202	191	315	253

Table 6 shows the results of the energy demand for every comfort model, as well as the percentage of variation (1-(main/reference)) and the difference (reference-main) in energy demand (where main is the studied local comfort model JPN_Adap_AC, and reference are the remaining models ASH_Adap_AC and JPN_Stat_AC used for comparison).

The results show a decrease in cooling energy demand of the adaptive local comfort model compared to ASHRAE 55 between 38 and 43 % (that is between 37 and 221 kWh/m^2·year) depending on the climate zone, where the average reduction is 40 %. Compared to the setpoint temperatures from the COOL BIZ campaign, the average is 41 %, however the reduction ranges between 25 and 52 % (that is between 20 and 315 kWh/m^2·year). In both cases, the highest reductions in cooling energy demand takes place in warmer climates. Oppositely, with regards to the heating energy demand, the reduction ranges compared to ASHRAE 55 between 27 and 57 %, although these percentages are not followed by the greater reductions in absolute terms, which takes place in colder

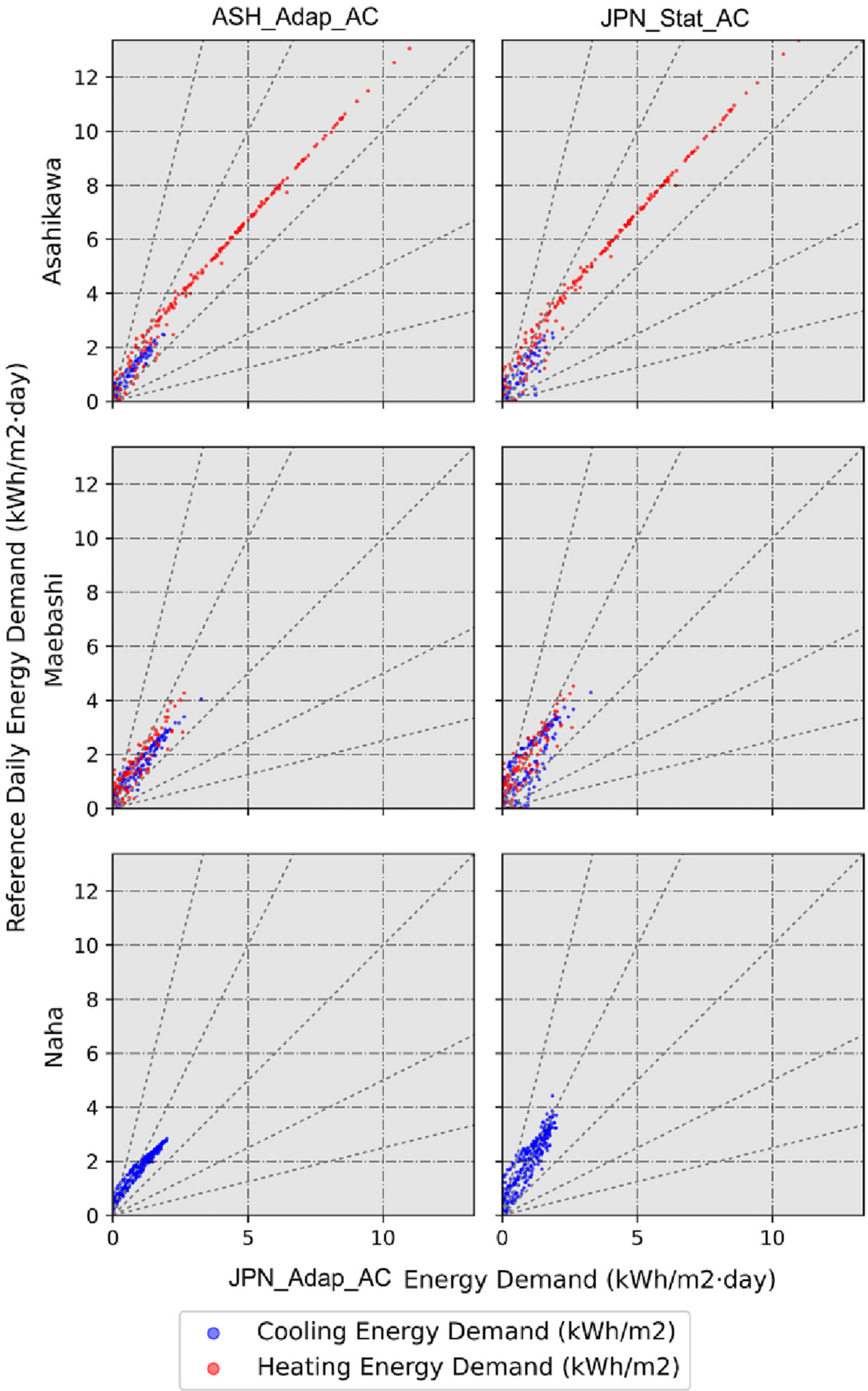

Fig. 5. Daily cooling and heating energy demand of JPN_Adap_AC compared to ASH_Adap_AC and JPN_Stat_AC.

climates. Compared to the COOL BIZ setpoint temperatures, there is a similar trend, ranging from 30 to 62 %. As a result of the cooling and heating energy trends, the total energy demand shows greater reductions in both cold and warm climates, while reductions at mild climates are less significant. Compared to ASHRAE 55, total energy demand ranges between 147 and 297 kWh/m^2·year, while compared to the COOL BIZ setpoint temperatures, ranges from 191 to 324 kWh/m^2·year, where the average percent reductions are 39 and 43 % respectively.

The relationship between the Japanese adaptive local model energy demand and ASHRAE 55's and COOL BIZ's is depicted in Fig. 5, where the first one is depicted in x-axis and the remaining in y-axis. The dashed lines are references to compare the energy demand: the central line is the 100 % reference line, which shows the same value for the Japanese adaptive model and the reference models, while the 2 remaining lines at both sides are the 50 % and 25 % reference lines. Since points above (or left hand side) the reference line represents reductions in the Japanese adaptive model compared to the reference models, these reductions take place generally in all climate zones and settings with some exceptions in Maebashi, although given the low values (roughly exceeding 1 kWh/m^2·day), these are not considered significant. In Asahikawa (cold climate), for ASHRAE 55's and COOL BIZ's the daily heating demand raises up to roughly 11 kWh/m^2·day and shows a clear linear correlation between the 100 % and 50 % reference lines, while the cooling demand slightly exceeds 2 kWh/m^2·day. Oppositely, the Japanese adaptive local model reaches roughly 8 and 2 kWh/m^2·day respectively for heating and cooling energy demand. In case of Maebashi (mild climate), the daily cooling and heating energy demands are similar, reaching 3 to 4 kWh/m^2·day in ASHRAE 55's and COOL BIZ's cases, while in case of the Japanese adaptive local model reaches 2 to 2.5 kWh/m^2·day. In case of Naha (warm climate), there is no heating energy demand in any case. Although the values are similar to the Maebashi climate, there is clearly a greater density of points around the 50 % reference line.

Table 7
Cooling, heating and total energy demand of JPN_Adap_MM compared to JPN_Adap_AC, ASH_Adap_AC and JPN_Stat_AC.

Operation mode	Comfort model	Climate zone								
		Asahikawa	Sapporo	Morioka	Niigata	Maebashi	Tokyo	Kagoshima	Naha	Average
Cooling Energy Demand (kWh/m2)	ASH_Adap_AC	96	96	153	215	243	264	319	511	237
	JPN_Stat_AC	82	79	145	229	265	295	357	605	257
	JPN_Adap_AC	58	59	92	127	148	155	187	290	140
	JPN_Adap_MM	15	14	31	51	76	82	93	134	62
	1-(JPN_Adap_MM/ASH_Adap_AC)	84%	86%	80%	76%	69%	69%	71%	74%	76%
	ASH_Adap_AC - JPN_Adap_MM	81	82	122	164	167	183	225	378	175
	1-(JPN_Adap_MM/JPN_Stat_AC)	82%	83%	79%	78%	71%	72%	74%	78%	77%
	JPN_Stat_AC - JPN_Adap_MM	67	65	114	177	189	213	264	472	195
	1-(JPN_Adap_MM/JPN_Adap_AC)	74%	77%	66%	60%	49%	47%	50%	54%	60%
	JPN_Adap_AC - JPN_Adap_MM	43	46	61	76	72	74	94	156	78
Heating Energy Demand (kWh/m2)	ASH_Adap_AC	944	790	500	258	177	88	47	0	351
	JPN_Stat_AC	985	824	529	277	194	100	52	0	370
	JPN_Adap_AC	685	562	318	143	98	38	32	0	235
	JPN_Adap_MM	687	563	320	144	99	38	33	0	235
	1-(JPN_Adap_MM/ASH_Adap_AC)	27%	29%	36%	44%	44%	56%	29%	0%	33%
	ASH_Adap_AC - JPN_Adap_MM	257	227	181	114	79	50	13	0	115
	1-(JPN_Adap_MM/JPN_Stat_AC)	30%	32%	40%	48%	49%	62%	36%	0%	37%
	JPN_Stat_AC - JPN_Adap_MM	298	261	210	133	95	62	19	0	135
	1-(JPN_Adap_MM/JPN_Adap_AC)	0%	0%	0%	0%	-1%	-2%	-5%	0%	-1%
	JPN_Adap_AC - JPN_Adap_MM	-2	-1	-1	-1	-1	-1	-2	0	-1
Total Energy Demand (kWh/m2)	ASH_Adap_AC	1040	886	653	473	420	352	365	511	588
	JPN_Stat_AC	1067	903	674	505	458	395	410	605	627
	JPN_Adap_AC	743	621	411	270	246	193	219	290	374
	JPN_Adap_MM	702	576	351	195	175	120	126	134	297
	1-(JPN_Adap_MM/ASH_Adap_AC)	33%	35%	46%	59%	58%	66%	65%	74%	55%
	ASH_Adap_AC - JPN_Adap_MM	338	310	302	278	245	233	239	378	290
	1-(JPN_Adap_MM/JPN_Stat_AC)	34%	36%	48%	61%	62%	70%	69%	78%	57%
	JPN_Stat_AC - JPN_Adap_MM	365	327	324	310	283	275	283	472	330
	1-(JPN_Adap_MM/JPN_Adap_AC)	6%	7%	15%	28%	29%	38%	42%	54%	27%
	JPN_Adap_AC - JPN_Adap_MM	41	45	60	75	71	73	92	156	77

3.2. Mixed-mode energy performance

The energy performance of the setpoint temperatures based on the Japanese adaptive local comfort model considering the mixed-mode approach (named JPN_Adap_MM) has been analysed and compared to the energy performance of the remaining comfort models considered in this paper, including the same model in full-air conditioning mode (JPN_Adap_AC, ASH_Adap_AC and JPN_Stat_AC).

Table 7 follows the same structure as the one related to the full air-conditioning mode. The results show reductions of the cooling, heating and total energy demand in the mixed-mode Japanese local adaptive model compared to ASRHAE 55's and COOL BIZ's setpoints. There have been also reductions compared to the same in full air-conditioning mode, except in the heating energy demand, where variations have been insignificant or even slightly unfavourable. The total energy demand reduction follows similar patterns to the full air-conditioning mode, however in this case, the warm climates achieve greater reductions, between 233 and 378 kWh/m^2·year compared to ASHRAE 55, between 275 and 472 kWh/m^2·year compared to COOL BIZ, and between 41 and 156 kWh/m^2·year compared to the same in full air-conditioning mode.

The relationship between the mixed-mode Japanese adaptive local model energy demand and the same in full air-conditioning mode, ASHRAE 55's and COOL BIZ's is depicted in Fig. 6, similarly to Fig. 5. Compared to ASHRAE 55 and COOL BIZ, the heating and cooling energy demand is lower in the mixed-mode Japanese adaptive local model in all cases. Again, a linear correlation is shown in Asahikawa climate, while no heating rate is needed in Naha climate. Compared to the same in full air-conditioning mode, heating energy demand is the same in both models, however important cooling energy demand reductions are achieved.

3.3. Impact of the climate change

To understand the extent of impact of climate change on the energy saving potential of the local adaptive setpoint temperatures, the energy performance has also been analysed considering all climate zones and RCP scenarios 2.6, 4.5 and 8.5 for years 2050 and 2100. Fig. 7 shows the variation of the energy demand in the different scenarios and climate zones. Regarding the cooling energy demand, most of the data ranges between 0 and 500 kWh/m^2·year, slightly exceeded only in RCP8.5 2100 in some climates. However, in Naha, the impact of the climate change is significantly severe, since energy demand according to both ASHRAE 55 and COOL BIZ already exceeds this limit at present scenario. In case of the heating energy demand, the greatest reductions take place at the cold climates, especially Asahikawa and Sapporo. These reductions decrease gradually until Naha, where there is no need to heat even in present scenario. As a result, the higher energy demands take place at the extreme climates, although energy demand variations in the Mixed-mode Japanese adaptive local model are smaller than the rest, and therefore this model is visibly less sensitive to the impact of climate change.

The variation in energy demand is shown in Tables A1–A3, in Appendix A, as percentages ("1-(Present/Scenario_Year)") and difference between values ("Scenario_Year - Present"), where reductions compared to Present scenario are negative values highlighted in green, increments compared to Present scenario are shown as positive red-highlighted values and no variations

Table 8
Variation in the hours in which ventilation was allowed depending on climate zone, scenario and year.

Scenarios	Hours in which ventilation was allowed								
	Asahikawa	Sapporo	Morioka	Niigata	Maebashi	Tokyo	Kagoshima	Naha	Average
Present	2147	2463	2540	3162	2913	3412	4083	5569	3286
RCP26_2050	2226	2370	2786	3028	2926	3444	4185	5391	3295
RCP26_2100	2252	2632	2434	3200	2845	3340	4142	5227	3259
RCP45_2050	2348	2715	2696	3012	3022	3380	4081	5221	3309
RCP45_2100	2484	2865	2923	3117	2992	3605	3996	5237	3403
RCP85_2050	2431	2691	2389	3132	3057	3457	4123	5077	3295
RCP85_2100	2416	3012	2729	2937	3367	3489	3848	4394	3274
1-(RCP26_2050/Present)	-4%	4%	-10%	4%	0%	-1%	-3%	3%	-1%
1-(RCP26_2100/Present)	-5%	-7%	4%	-1%	2%	2%	-1%	6%	0%
1-(RCP45_2050/Present)	-9%	-10%	-6%	5%	-4%	1%	0%	6%	-2%
1-(RCP45_2100/Present)	-16%	-16%	-15%	1%	-3%	-6%	2%	6%	-6%
1-(RCP85_2050/Present)	-13%	-9%	6%	1%	-5%	-1%	-1%	9%	-2%
1-(RCP85_2100/Present)	-13%	-22%	-7%	7%	-16%	-2%	6%	21%	-3%
Present - RCP26_2050	-79	93	-246	133	-13	-32	-102	177	-9
Present - RCP26_2100	-106	-170	106	-38	67	72	-59	341	27
Present - RCP45_2050	-201	-252	-156	150	-109	32	2	347	-23
Present - RCP45_2100	-338	-402	-383	45	-80	-193	87	332	-117
Present - RCP85_2050	-284	-228	151	30	-144	-45	-41	492	-9
Present - RCP85_2100	-269	-550	-189	224	-455	-77	235	1175	12

are not highlighted. The energy demand is also shown, highlighted in yellow. In case of the cooling energy demand, it generally increases, although it is significantly more severe in warmer climates, especially for model based on COOL BIZ setpoint temperatures. The average increase for Japanese local adaptive model ranges between 17 and 50 % (25 and 123 kWh/m^2·year) for full air-conditioning, and between 28 and 68 % (21 and 111 kWh/m^2·year) for mixed-mode. Oppositely, in case of the heating energy demand, there is general reduction, greater in colder climates and again especially for the model based on COOL BIZ setpoint temperatures, thus being very sensitive to climate change. The average reduction for the Japanese local adaptive model in heating energy demand ranges from 49 to 155 kWh/m^2·year in full air-conditioning, and between 48 and 156 kWh/m^2·year in mixed-mode. This small difference is consistent with the previous results, confirming that heating energy demand is not affected by mixed-mode. Finally, the total energy demand shows different trends depending on the climate zone: in case of Asahikawa, Sapporo and Morioka, the reduction in heating demand prevails over the increase in cooling demand; oppositely, in case of the Tokyo, Kagoshima and Naha, the cooling demand prevails over the heating demand, and therefore, the total energy demand increases; in case of the mild climates (Niigata and Maebashi), both demands are very similar, and therefore there is no significant variation.

Since one of the most important impacts of climate change is the increase of temperature, it also has an effect on the natural ventilation and the performance of mixed mode. Fig. 8 shows the average of the air change rate at every hour in the summer months, for the climates of Asahikawa, Maebashi and Naha. It shows the variability of the different scenarios, where the most severe scenarios are below the remaining, especially RCP8.5 in 2100. This is reflected on the trends in the changes of the number of hours in

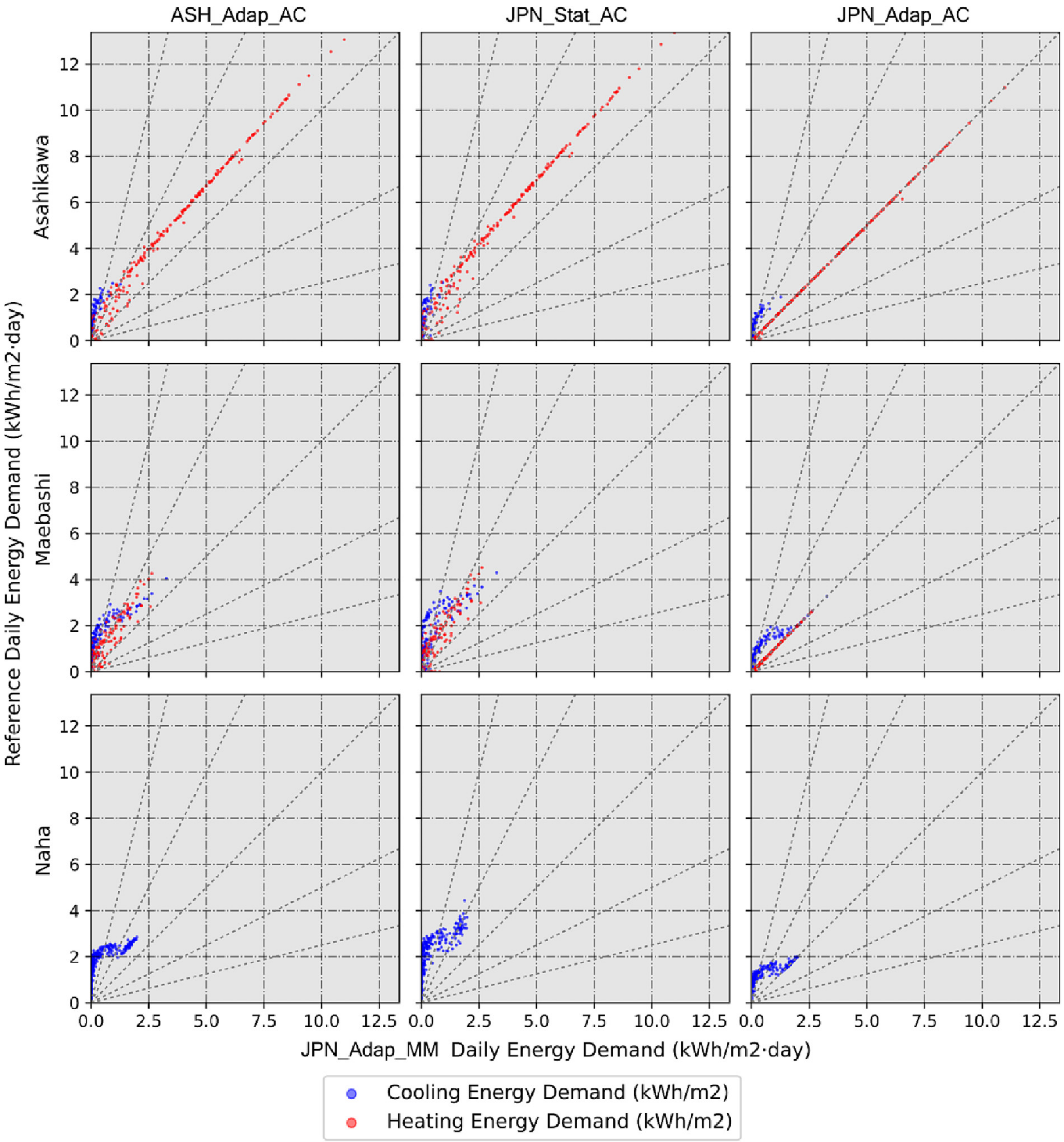

Fig. 6. Daily cooling and heating energy demand of JPN_Adap_MM compared to JPN_Adap_AC, ASH_Adap_AC and JPN_Stat_AC.

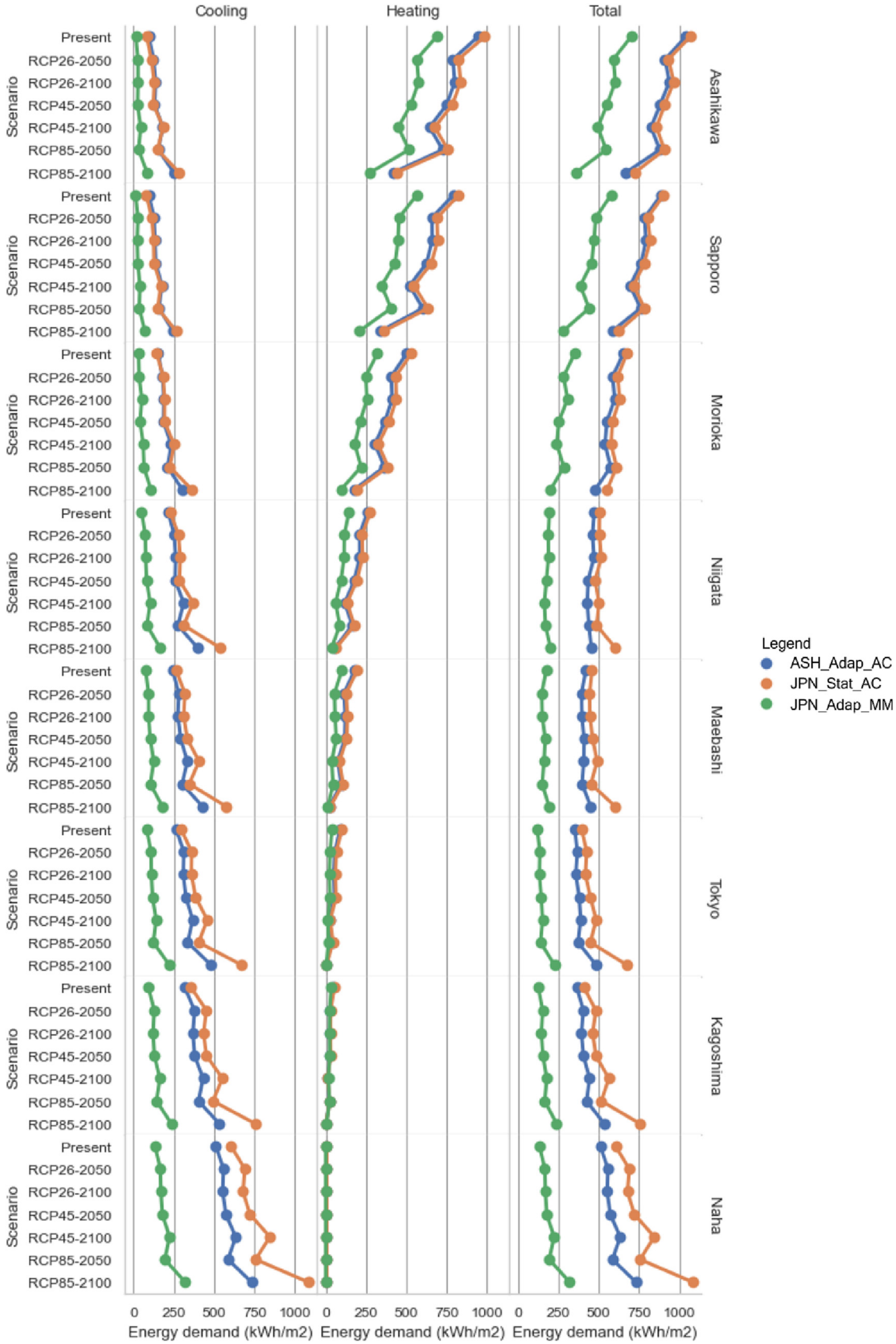

Fig. 7. Variation of the cooling, heating and total energy demand in the evolution of the scenarios in the different climate zones.

which ventilation was allowed, in Table 8. This table shows the ventilation hours depending on the different combinations of scenario and year (following the pattern "Scenario_Year"), as well as the comparison with Present scenario as percentages ("1-(Present/Scenario_Year)") and difference between values ("Scenario_Year - Present"). The ventilation hours increase towards the

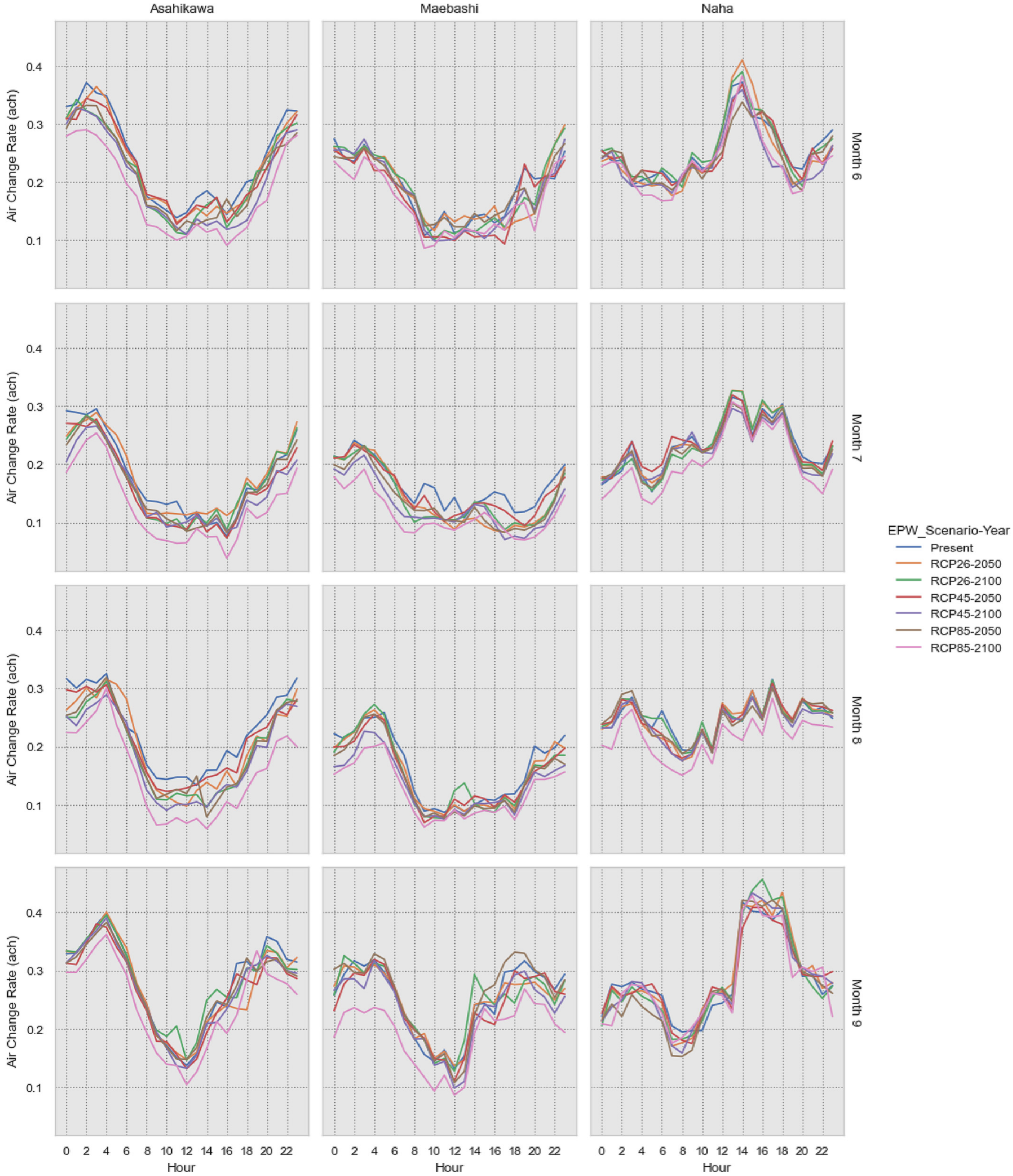

Fig. 8. Average hourly air change rate in the apartment, depending on climate zone, summer month, scenario and year.

warm climates, while the climate change has a different impact on each of them. In cold climates, the temperature is not generally acceptable for ventilation since it is too low, therefore the number of ventilation hours are very low. In this case, the global warming makes the temperature acceptable in more hours. Therefore, the impact is generally beneficial in cold climates, since the number of ventilation hours increase, although this is not significant compared to the harmful impact, such as the increase of floods between other risks. Oppositely, in warm climates, especially in Naha, the global warming make temperature to exceed acceptable limits and therefore, the number of ventilation hours is reduced, reaching the most severe values in RCP8.5, with a reduction of 9 and 21 % in 2050 and 2100 respectively. In mild climates, different patterns can be found, however the most frequent shows an increase of ventilation hours in year 2050 and a decrease in year 2100, since the temperature has exceeded acceptable limits.

The ability to estimate adaptive thermal comfort levels for future scenarios is constrained since the adaptability to rising temperatures has not been taken into account, therefore some inaccuracies have been introduced. Due to the fact that human being would find greater temperatures to be acceptable, adaptive setpoint temperatures are expected to be higher than actually predicted if thermal adaptation were taken into account, which would lead to greater energy savings.

4. Conclusions

Recent studies have provided evidence of the energy saving potential of using setpoint temperatures based on adaptive comfort models, however these studies have focused to the application of the international standards ASHRAE 55 and EN 16798-1. In this case, a Japanese local adaptive comfort model has been considered for the application of setpoint temperatures, and results of energy demand have been compared to those from the ASHRAE 55 and the COOL BIZ campaign (18–28 °C). In order to evaluate the performance of the Japanese local adaptive comfort model, a selection of 8 different climate zones based on the Japanese regulation have been considered, as well as the projections under the influence of climate change in scenarios RCP2.6, 4.5 and 8.5 in years 2050 and 2100. The accurate representation of the energy demand has been achieved by using an apartment representative of the Japanese dwellings, built after the Second World War in 1951, named after that year: The 51C. To be able to apply these setpoint temperatures based on the Japanese local comfort model, it needed to be previously added to the software which shapes the technological framework in which the building energy simulations are performed: the Python package called 'accim'.

The results of using the Japanese local adaptive comfort model show significant energy savings ranging between 29 and 52 % (147 and 324 kWh/m^2·year) in case of the full air-conditioning mode, and between 33 and 78 % (233 and 472 kWh/m^2·year) in case of the mixed-mode, depending on the climate zone, and model compared to. In the context of climate change, cold climates (Asahikawa, Sapporo and Morioka) present reductions in total energy demand compared to Present scenario, ranging between 14 and 65 % for full air-conditioning mode, and between 18 and 91 % for mixed mode. Oppositely, warm climates (Tokyo, Kagoshima and Naha) present increments in the total energy demand, between 8 and 36 % for full air-conditioning mode, and between 17 and 51 % for mixed-mode. In case of the mild climates (Niigata and Maebashi), variations are not significant, since heating and cooling demands are roughly compensated. It must be borne in mind that all simulation results based on the use of adaptive setpoint temperatures have been obtained using the adaptive models for free-running buildings, hence assuming high levels of adaptation.

Therefore, this study identifies the use of setpoint temperatures based on this Japanese local adaptive comfort model as a powerful energy saving strategy. However, more research is needed to get to know the potential of using local adaptive comfort models around the world. Future research lines will consist on the development of accis to perform building energy simulations with local adaptive comfort models in different areas.

CRediT authorship contribution statement

Daniel Sánchez-García: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **David Bienvenido-Huertas:** Conceptualization, Investigation, Formal analysis. **Jesús A. Pulido-Arcas:** Visualization, Investigation, Validation. **Carlos Rubio-Bellido:** Visualization, Investigation, Validation.

Data availability

The authors do not have permission to share data.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

See Tables A1–A3.

Table A1
Variation of the cooling energy demand depending on the arguments ComfStand, ComfMod, HVACmode and climate zone.

Operation mode	ComfStand	ComfMod	HVACmode	Climate zone	Scenario																		
					Present	RCP26_2050	RCP26_2100	RCP45_2050	RCP45_2100	RCP85_2050	RCP85_2100	1-(Present/RCP26_2050)	1-(Present/RCP26_2100)	1-(Present/RCP45_2050)	1-(Present/RCP45_2100)	1-(Present/RCP85_2050)	1-(Present/RCP85_2100)	RCP26_2050 - Present	RCP26_2100 - Present	RCP45_2050 - Present	RCP45_2100 - Present	RCP85_2050 - Present	RCP85_2100 - Present
Cooling	ASHRA E55	Adaptive	Full Air-Conditioning	Asahikawa	96	124	138	131	181	154	250	22%	30%	27%	47%	37%	61%	28	41	35	85	57	154
				Sapporo	96	127	133	139	176	157	245	24%	28%	31%	45%	39%	61%	31	37	42	80	61	149
				Morioka	153	180	188	185	234	211	302	15%	19%	18%	35%	28%	49%	27	35	33	81	59	149
				Niigata	215	252	261	258	310	275	398	15%	18%	17%	31%	22%	46%	37	46	43	95	61	183
				Maebashi	243	280	275	292	334	301	429	13%	12%	17%	27%	19%	43%	38	32	49	91	58	186
				Tokyo	264	312	308	325	366	336	481	15%	14%	19%	28%	21%	45%	47	44	61	102	71	217
				Kagoshima	319	378	367	379	431	402	531	16%	13%	16%	26%	21%	40%	59	49	60	112	84	213
				Naha	511	558	553	572	633	586	730	8%	8%	11%	19%	13%	30%	47	42	61	122	75	219
				Average	**237**	**276**	**278**	**285**	**333**	**303**	**421**	**16%**	**18%**	**19%**	**32%**	**25%**	**47%**	**39**	**41**	**48**	**96**	**66**	**184**
	Japanese model	Static	Full Air-Conditioning	Asahikawa	82	111	130	124	184	149	283	26%	37%	34%	55%	45%	71%	29	48	42	102	67	201
				Sapporo	79	113	126	128	169	150	264	30%	37%	38%	53%	47%	70%	34	47	49	90	71	185
				Morioka	145	183	194	192	251	225	360	21%	25%	25%	42%	36%	60%	38	49	47	106	80	215
				Niigata	229	278	289	284	369	311	539	18%	21%	20%	38%	26%	58%	50	60	56	141	82	311
				Maebashi	265	318	312	332	406	345	576	17%	15%	20%	35%	23%	54%	54	47	68	141	81	312
				Tokyo	295	360	358	385	457	404	672	18%	18%	23%	35%	27%	56%	66	64	90	162	109	377
				Kagoshima	357	452	434	452	551	492	754	21%	18%	21%	35%	27%	53%	94	76	95	193	135	396
				Naha	605	689	679	721	845	756	1083	12%	11%	16%	28%	20%	44%	84	74	115	239	151	477
				Average	**257**	**313**	**315**	**327**	**404**	**354**	**566**	**20%**	**23%**	**25%**	**40%**	**32%**	**58%**	**56**	**58**	**70**	**147**	**97**	**309**
		Adaptive	Full Air-conditioning	Asahikawa	58	79	86	79	115	97	156	27%	33%	27%	49%	40%	63%	21	28	21	56	39	98
				Sapporo	59	78	78	84	108	97	150	24%	24%	29%	45%	39%	60%	19	19	25	49	38	90
				Morioka	92	105	116	108	142	131	184	12%	20%	15%	35%	29%	50%	12	23	16	50	39	91
				Niigata	127	151	159	154	191	165	253	16%	20%	18%	34%	23%	50%	24	32	27	65	39	127
				Maebashi	148	169	166	179	203	179	271	12%	11%	17%	27%	17%	45%	21	18	30	55	31	122
				Tokyo	155	186	183	194	220	199	306	17%	15%	20%	30%	22%	49%	31	28	39	65	44	151
				Kagoshima	187	225	219	227	265	244	337	17%	15%	18%	29%	23%	45%	39	32	40	78	57	150
				Naha	290	322	318	330	374	343	447	10%	9%	12%	23%	16%	35%	32	29	40	84	53	157
				Average	**140**	**165**	**166**	**169**	**202**	**182**	**263**	**17%**	**18%**	**19%**	**34%**	**26%**	**50%**	**25**	**26**	**30**	**63**	**42**	**123**
			Mixed-mode	Asahikawa	15	27	28	25	45	32	84	45%	46%	40%	66%	53%	82%	12	13	10	30	17	69
				Sapporo	14	27	23	27	40	36	71	50%	40%	49%	66%	62%	81%	14	9	13	27	22	57
				Morioka	31	35	51	40	60	65	107	11%	40%	23%	49%	52%	71%	4	20	10	29	34	76
				Niigata	51	73	75	82	103	84	165	30%	32%	38%	50%	39%	69%	22	24	31	51	33	114
				Maebashi	76	93	93	104	125	105	180	19%	18%	27%	39%	27%	58%	17	17	28	49	29	104
				Tokyo	82	109	110	118	140	123	223	25%	26%	31%	42%	34%	63%	27	29	37	59	41	141
				Kagoshima	93	128	122	130	163	143	234	27%	24%	28%	43%	35%	60%	35	29	36	70	50	141
				Naha	134	167	170	178	224	194	320	20%	21%	25%	40%	31%	58%	34	36	45	90	60	186
				Average	**62**	**83**	**84**	**88**	**113**	**98**	**173**	**28%**	**31%**	**33%**	**49%**	**42%**	**68%**	**21**	**22**	**26**	**51**	**36**	**111**

Table A2
Variation of the heating energy demand depending on the arguments ComfStand, ComfMod, HVACmode and climate zone.

Operation mode	ComfStand	ComfMod	HVACmode	Climate zone	Scenario																	
					Present	RCP26_2050	RCP26_2100	RCP45_2050	RCP45_2100	RCP85_2050	RCP85_2100	1-(Present/RCP26_2050)	1-(Present/RCP26_2100)	1-(Present/RCP45_2050)	1-(Present/RCP45_2100)	1-(Present/RCP85_2050)	1-(Present/RCP85_2100)	RCP26_2050 - Present	RCP26_2100 - Present	RCP45_2050 - Present	RCP45_2100 - Present	RCP85_2050 - Present	RCP85_2100 - Present
Heating	ASHRA E55	Adaptive	Full Air-Conditioning	Asahikawa	944	788	800	750	644	725	419	-20%	-18%	-26%	-47%	-30%	-125%	-156	-144	-194	-300	-219	-525
				Sapporo	790	658	659	625	519	602	340	-20%	-20%	-26%	-52%	-31%	-133%	-132	-130	-165	-271	-188	-450
				Morioka	500	407	412	366	306	363	177	-23%	-21%	-37%	-64%	-38%	-182%	-93	-89	-134	-195	-137	-323
				Niigata	258	210	210	178	119	164	57	-23%	-23%	-45%	-117%	-57%	-351%	-48	-48	-80	-139	-94	-201
				Maebashi	177	113	121	118	74	96	23	-56%	-47%	-51%	-139%	-84%	-688%	-64	-56	-60	-103	-81	-155
				Tokyo	88	56	50	55	22	37	4	-57%	-77%	-62%	-296%	-141%	-2211%	-32	-38	-34	-66	-52	-84
				Kagoshima	47	27	26	27	12	23	3	-71%	-79%	-70%	-274%	-105%	-1446%	-19	-21	-19	-34	-24	-44
				Naha	0	0	0	0	0	0	0												
				Average	**351**	**282**	**285**	**265**	**212**	**251**	**128**	**-39%**	**-41%**	**-45%**	**-141%**	**-70%**	**-734%**	**-68**	**-66**	**-86**	**-139**	**-99**	**-223**
	Japanese model	Static	Full Air-Conditioning	Asahikawa	985	822	836	785	675	759	441	-20%	-18%	-25%	-46%	-30%	-123%	-163	-150	-200	-310	-227	-544
				Sapporo	824	689	693	655	547	634	361	-20%	-19%	-26%	-51%	-30%	-128%	-135	-131	-169	-277	-191	-463
				Morioka	529	434	438	393	326	386	193	-22%	-21%	-35%	-62%	-37%	-175%	-95	-92	-136	-203	-143	-337
				Niigata	277	226	228	194	133	177	65	-23%	-21%	-43%	-109%	-56%	-327%	-51	-49	-83	-144	-100	-212
				Maebashi	194	126	134	130	84	107	28	-53%	-44%	-49%	-130%	-81%	-599%	-67	-60	-63	-109	-86	-166
				Tokyo	100	65	60	64	28	45	4	-53%	-68%	-57%	-259%	-125%	-2212%	-35	-41	-36	-72	-56	-96
				Kagoshima	52	31	30	30	12	25	2	-71%	-76%	-71%	-329%	-108%	-2943%	-22	-23	-22	-40	-27	-50
				Naha	0	0	0	0	0	0	0												
				Average	**370**	**299**	**302**	**281**	**226**	**266**	**137**	**-37%**	**-38%**	**-44%**	**-141%**	**-67%**	**-930%**	**-71**	**-68**	**-89**	**-145**	**-104**	**-233**
		Adaptive	Full Air-conditioning	Asahikawa	685	563	575	526	449	514	275	-22%	-19%	-30%	-52%	-33%	-149%	-122	-111	-159	-236	-171	-410
				Sapporo	562	453	447	430	345	404	208	-24%	-26%	-31%	-63%	-39%	-170%	-109	-115	-132	-217	-158	-354
				Morioka	318	247	253	212	179	218	94	-29%	-26%	-50%	-78%	-46%	-240%	-72	-65	-106	-139	-100	-225
				Niigata	143	114	113	94	60	86	35	-26%	-27%	-52%	-138%	-67%	-307%	-29	-30	-49	-83	-57	-108
				Maebashi	98	52	56	64	35	44	13	-86%	-74%	-53%	-177%	-123%	-663%	-45	-41	-34	-62	-54	-85
				Tokyo	38	27	22	26	12	17	4	-42%	-75%	-48%	-221%	-127%	-951%	-11	-16	-12	-26	-21	-34
				Kagoshima	32	24	22	24	14	22	4	-35%	-46%	-35%	-128%	-46%	-693%	-8	-10	-8	-18	-10	-28
				Naha	0	0	0	0	0	0	0												
				Average	**235**	**185**	**186**	**172**	**137**	**163**	**79**	**-87%**	**-24%**	**-25%**	**-95%**	**-48%**	**-384%**	**-50**	**-49**	**-63**	**-98**	**-72**	**-155**
			Mixed-mode	Asahikawa	687	564	576	527	450	515	277	-22%	-19%	-30%	-52%	-33%	-148%	-123	-111	-160	-236	-172	-410
				Sapporo	563	454	448	430	346	405	209	-24%	-26%	-31%	-63%	-39%	-169%	-109	-114	-132	-217	-158	-354
				Morioka	320	248	256	213	180	219	95	-29%	-25%	-50%	-78%	-46%	-235%	-72	-64	-106	-140	-100	-224
				Niigata	144	115	114	95	61	87	36	-25%	-27%	-52%	-136%	-66%	-297%	-29	-30	-49	-83	-57	-108
				Maebashi	99	54	57	65	37	45	14	-83%	-73%	-52%	-170%	-118%	-620%	-45	-42	-34	-62	-54	-85
				Tokyo	38	27	22	26	12	17	4	-42%	-73%	-46%	-211%	-123%	-869%	-11	-16	-12	-26	-21	-34
				Kagoshima	33	25	23	25	15	23	5	-34%	-43%	-32%	-119%	-43%	-635%	-8	-10	-8	-18	-10	-29
				Naha	0	0	0	0	0	0	0												
				Average	**235**	**186**	**187**	**173**	**138**	**164**	**80**	**-37%**	**-23%**	**-25%**	**-91%**	**-48%**	**-359%**	**-50**	**-48**	**-63**	**-98**	**-72**	**-156**

Table A3
Variation of the total energy demand depending on the arguments ComfStand, ComfMod, HVACmode and climate zone.

Operation mode	ComfStand	ComfMod	HVACmode	Climate zone	Scenario																		
					Present	RCP26_2050	RCP26_2100	RCP45_2050	RCP45_2100	RCP85_2050	RCP85_2100	1-(Present/RCP26_2050)	1-(Present/RCP26_2100)	1-(Present/RCP45_2050)	1-(Present/RCP45_2100)	1-(Present/RCP85_2050)	1-(Present/RCP85_2100)	RCP26_2050 - Present	RCP26_2100 - Present	RCP45_2050 - Present	RCP45_2100 - Present	RCP85_2050 - Present	RCP85_2100 - Present
Total	ASHRA E55	Adaptive	Full Air-Conditioning	Asahikawa	1040	912	937	881	825	878	668	-14%	-11%	-18%	-26%	-18%	-56%	-128	-103	-159	-215	-162	-372
				Sapporo	886	785	793	763	695	759	585	-13%	-12%	-16%	-27%	-17%	-52%	-101	-93	-123	-191	-127	-301
				Morioka	653	587	599	551	539	575	479	-11%	-9%	-18%	-21%	-14%	-36%	-66	-53	-102	-113	-78	-174
				Niigata	473	462	471	435	429	439	455	-2%	0%	-9%	-10%	-8%	-4%	-11	-2	-38	-44	-33	-18
				Maebashi	420	394	396	410	408	397	451	-7%	-6%	-3%	-3%	-6%	7%	-26	-24	-11	-12	-23	31
				Tokyo	352	368	358	380	389	372	485	4%	2%	7%	9%	5%	27%	15	6	27	36	20	132
				Kagoshima	365	405	394	406	443	425	534	10%	7%	10%	18%	14%	32%	40	28	41	78	60	169
				Naha	511	558	553	572	633	586	730	8%	8%	11%	19%	13%	30%	47	42	61	122	75	219
				Average	**588**	**559**	**563**	**550**	**545**	**554**	**549**	**-3%**	**-3%**	**-4%**	**-5%**	**-4%**	**-6%**	**-29**	**-25**	**-38**	**-42**	**-34**	**-39**
	Japanese model	Static	Full Air-Conditioning	Asahikawa	1067	933	965	909	859	907	724	-14%	-11%	-17%	-24%	-18%	-47%	-134	-102	-158	-208	-160	-343
				Sapporo	903	803	819	783	716	784	625	-13%	-10%	-15%	-26%	-15%	-44%	-100	-84	-120	-187	-120	-278
				Morioka	674	618	631	585	577	611	553	-9%	-7%	-15%	-17%	-10%	-22%	-57	-43	-89	-97	-63	-121
				Niigata	505	504	517	478	502	488	604	0%	2%	-6%	-1%	-4%	16%	-1	12	-27	-3	-17	99
				Maebashi	458	445	446	463	490	453	604	-3%	-3%	1%	7%	-1%	24%	-14	-13	5	32	-6	146
				Tokyo	395	426	418	449	485	449	676	7%	6%	12%	19%	12%	42%	31	23	54	90	54	281
				Kagoshima	410	482	463	483	563	517	755	15%	12%	15%	27%	21%	46%	73	54	73	153	108	346
				Naha	605	689	679	721	845	756	1083	12%	11%	16%	28%	20%	44%	84	74	115	239	151	477
				Average	**627**	**612**	**617**	**609**	**630**	**621**	**703**	**-1%**	**0%**	**-1%**	**2%**	**1%**	**7%**	**-15**	**-10**	**-18**	**2**	**-7**	**76**
		Adaptive	Full Air-conditioning	Asahikawa	743	642	661	605	564	611	431	-16%	-12%	-23%	-32%	-22%	-73%	-101	-82	-138	-179	-132	-312
				Sapporo	621	532	526	513	453	501	358	-17%	-18%	-21%	-37%	-24%	-74%	-90	-96	-108	-168	-120	-263
				Morioka	411	351	369	320	321	349	277	-17%	-11%	-28%	-28%	-18%	-48%	-59	-42	-90	-89	-62	-133
				Niigata	270	265	272	248	251	251	289	-2%	1%	-9%	-7%	-7%	6%	-5	2	-22	-19	-19	19
				Maebashi	246	221	223	242	239	223	283	-11%	-10%	-1%	-3%	-10%	13%	-24	-23	-4	-7	-23	38
				Tokyo	193	213	205	220	232	216	309	9%	6%	12%	17%	11%	38%	20	12	27	39	23	117
				Kagoshima	219	249	241	251	279	266	341	12%	9%	13%	22%	18%	36%	30	22	32	60	47	123
				Naha	290	322	319	330	374	343	447	10%	9%	12%	23%	16%	35%	32	29	40	85	53	157
				Average	**374**	**349**	**352**	**341**	**339**	**345**	**342**	**-4%**	**-3%**	**-6%**	**-6%**	**-5%**	**-8%**	**-25**	**-22**	**-33**	**-35**	**-29**	**-32**
			Mixed-mode	Asahikawa	702	591	603	552	495	547	360	-19%	-16%	-27%	-42%	-28%	-95%	-111	-98	-150	-207	-155	-341
				Sapporo	576	482	471	457	386	441	280	-20%	-22%	-26%	-49%	-31%	-106%	-95	-105	-120	-190	-136	-297
				Morioka	351	283	307	254	240	284	203	-24%	-14%	-38%	-46%	-23%	-73%	-68	-44	-97	-111	-66	-148
				Niigata	195	188	189	177	164	170	202	-4%	-3%	-10%	-19%	-14%	3%	-7	-6	-18	-31	-25	7
				Maebashi	175	147	150	169	162	150	193	-19%	-16%	-3%	-8%	-17%	10%	-28	-25	-6	-13	-25	18
				Tokyo	120	136	133	144	153	140	227	12%	10%	17%	21%	14%	47%	16	13	24	33	20	107
				Kagoshima	126	153	145	155	179	166	239	18%	13%	18%	29%	24%	47%	27	19	28	52	40	113
				Naha	134	167	170	178	224	194	320	20%	21%	25%	40%	31%	58%	34	36	45	90	60	187
				Average	**297**	**268**	**271**	**261**	**250**	**261**	**253**	**-4%**	**-4%**	**-6%**	**-9%**	**-6%**	**-14%**	**-29**	**-26**	**-37**	**-47**	**-36**	**-44**

Appendix B. Supplementary material

There are more supplementary materials related to accim in the following websites:

- Web repository: https://github.com/dsanchez-garcia/accim.
- Python Package Index (PyPI): https://pypi.org/project/accim/.
- Documentation: https://accim.readthedocs.io/en/master/.

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