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**Morning surge in sympathetic nervous activity in the indoor environment  
during the cold winter season**

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## **Abstract**

We addressed to the sympathetic nervous activation of the same people in both their houses and a highly insulated and airtight model house (model house) during the cold winter season. Eight subjects (4 males and 4 females) stayed two nights at each house and were continuously monitored for sympathetic nerve system by calculating LF (low frequency) / HF (high frequency) in the analysis of heart rate variability using a wearable electrocardiography equipment. The room temperatures were kept constant at 20 °C or more in model house, but much lower in their houses. In all subjects, the sleeping duration is longer in model house compared with that in the participants' houses. Four subjects showed a morning surge in sympathetic activity that were more intense at their houses. This morning surge in sympathetic activity in a residential setting suggests the importance of the indoor environment in the management of early morning hypertension.

## Introduction

Blood pressure (BP) fluctuations including morning surges can be triggered by combination of several stressors, such as physical exertion, and severe emotional and environmental stress. Morning BP surge are augmented in cold seasons, and cold temperature has an impact on the BP surge. We and others have reported that indoor temperature showed increased blood pressure with fluctuation, which might lead to high cardiovascular mortality in the winter season [1-4]. Activation of the sympathetic nervous system in response to cold temperature increases vascular tone in resistance arteries, and bedtime administration of an  $\alpha$ -adrenergic blocker suppresses morning BP surge by reducing resistance [5]. The rhythmic components of heart rate variability can be separated and quantitatively assessed by means of power spectral analysis, which can be associated with autonomic nervous system activity [6, 7]. In this study, we focused on the real time analysis of sympathetic nervous system by frequency domain analysis of heart rate variability signals using wearable electrocardiography devices, when the same subjects spent two days each at their home and in a highly insulated, airtight model house (model house). We also measured the accurate and continuous indoor temperature using fixed thermos sensor at living room, bedroom and dressing room.

## **Methods**

### ***Study Protocol***

This study protocol was approved by the Faculty of Architecture, Kindai University Ethics Committee (2020-1). All subjects were enrolled in this study from Dec 2021 to Feb 2022 during winter season. Four subjects (1-4) stayed at their homes for two days and then stayed at the model house for two days, and the other four subjects (5-8) did the opposite. Basically, they stayed in the indoor environment all day. Because the participants could not be relaxed in a new environment on the first day, we focused on the analysis from the second day in both houses, except for the case of Subject 8 at their house. Subject 8 did not sleep in their home at all on the second day.

### ***The highly insulated and airtight model house (model house) and temperature measurements***

The model house is a two-story wooden detached house with a total floor area of 130.08 m<sup>2</sup> located in Sakaimachi, Sashima-gun, Ibaraki Prefecture in Japan (Asahi Kasei Construction Materials Corporation). The house has a UA value of 0.20 W/(m<sup>2</sup>-K) and a C value of 0.12 cm<sup>2</sup>/m<sup>2</sup>. The UA value indicates the exterior skin average heat transfer coefficient, a standard that indicates the heat insulation performance of a building, with

smaller values indicating higher performance; the C-value is the equivalent clearance area, an indicator of the airtightness of a building: the smaller the value is, the higher the performance, which is an index of the degree of high heat insulation and airtightness. This house achieves a comfortable temperature environment by combining a performance that far exceeds the national heat insulation standard with energy-saving equipment. The indoor environments in the subjects' homes and the model house were recorded by installing data loggers equipped with temperature and humidity sensors in various rooms and taking continuous measurements at 10-minute intervals.

### **Sympathetic nervous activity by frequency domain analysis of heart rate variability**

The rhythmic components of heart rate variability can be separated and quantitatively assessed by means of power spectral analysis. The powers of high frequency (HF) and low frequency (LF) components of heart rate variability have been shown to estimate cardiac vagal and sympathetic activities, and LF/HF ratio is a marker of sympathetic nervous system activity [6. 7]. Eight subjects (four males and four females) carried portable electrocardiography (Heartnote, JSR corporation, Tokyo) devices that were capable of simultaneously measuring heart rate, CVRR (coefficient of variation of R-R interval), LF, HF and physical activity throughout the day. Sleeping duration was determined by the monitoring of continuous physical activity. Sympathetic activation was

defined as showing more than +2 SDs for distribution within an individual in terms of the LF/HF ratio calculated every 10 seconds. The sympathetic activity analysis of Subject 7 and 8 at first day (model house) was incomplete due to accidental reasons.

## **Results and Discussion**

Regarding indoor temperature measurements, room temperatures were kept constant at 20 °C or more in the model house. However, in the participants' houses, temperatures were low with large temperature differences between rooms, and in one case, the room temperature in the bedroom was recorded at 6.3 °C (Figure 1). Interestingly, sleeping duration in model house was longer than that in the participants' houses for all subjects (Table 1 and Supplementary Figure 1 and 2). This suggests that the room temperature in model house was comfortable for sleeping.

In the analysis of sympathetic nerve system, the average heart rate, HF, LF/HF and CVRR scores on the second day at the participants' houses were not different from that at the model house (Table 1 and Supplementary Figure 1 and 2) We further focused on the time windows of waking hours. Waking hours are the time when most cardiovascular events occur due to the morning surge in blood pressure, which might be caused by the activation of sympathetic nervous system. As shown in Figure 1, four subjects showed a morning surge in the sympathetic nervous system immediately after

waking up. Subject 5 (hypertensive patient taking antihypertensive drug) and 7 (Crohn's disease patient) showed a morning surge at their houses. Subject 1 (obese) and 6 (no current disease) showed the morning surge at both houses and greater sympathetic nervous activity at their home. The physical activity was not correlated with the morning surge (Supplementary Figure 3). These results suggest that a comfortable temperature may attenuate the morning surge immediately after waking.

The WHO Housing and Health Guidelines recommend a minimum indoor temperature of 18 °C to prevent cold-related diseases. In a recent cross-sectional analysis in Japan, the average temperature in living rooms and bedrooms was 16.8 °C and 12.8 °C, respectively [8]. In contrast, in UK homes, the average living room and bedroom temperatures in the winter were 19.3 °C and 18.9 °C, respectively [9]. Furthermore, in New York, the average room living room temperature in the winter was 23.3 °C [10]. Interestingly, countries with severe winter climates (i.e., Finland or Sweden) tend to have warmer indoor temperatures, which are associated with lower excess mortality during the winter [11]. These findings suggest associations between better housing quality and lower winter excess mortality. A few recent reports showed the relationship between indoor temperatures and BP in Japan [12-14]. Saeki et al. reported that the indoor temperature showed strong associations with daytime SBP, nocturnal BP and morning BP surge [12].



Umishio et al. also showed that systolic blood pressure in the morning had a significantly higher sensitivity to changes in the indoor temperature (8.2 mm Hg increase/10 °C decrease) than that in the evening (6.5 mm Hg increase/10 °C decrease) [13]. They also suggest that the low indoor temperature in Japan might be a risk of morning surge of BP.

This study has the following limitations. First, the sample size was small and had large individual differences of sympathetic nerve activity. We cannot form conclusions from the results, however, a confirmatory study will be designed based on this exploratory result. Second, BP is affected by sleep duration and psychological factors. In this study, sleeping duration was longer in the model house for all subjects, which might be directly associated with the extent of morning surge. This can be further evaluated in the future. Third, we cannot conclude the association of morning BP surge with sympathetic activation because we did not have BP data. A wearable device that monitors both BP and HR will help us to evaluate this association.

During the COVID-19 pandemic, people stayed home and were stressed throughout these two years [15]. To prevent cardiovascular events at home, a suitable indoor thermal environment should be implemented society-wide, especially in the winter season.

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***Author contributions:*** H.N., H.A., H.O., A.I., and H.Y.: Study design and concept analysis. H.A., H.O., S.T., K.S., and N.K.: Data collection and support for analysis. H.N. wrote the manuscript. All authors drafted the manuscript and approved the final version for submission.

#### **Compliance with ethical standards**

#### ***Conflict of interest statement***

The Department of Health Development and Medicine is an endowed department supported by Angas, Daicel, and FunPep. Hiroshi Akiyama and Hiroki Otsuka are employees of the Asahi Kasei Construction Materials Corporation. These organization did not have any additional role in the data analysis, decision to publish, or description of Results section of the manuscript.

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### **Figure legend**

#### **LF/HF ratio (sympathetic nerve system) and indoor temperature during 2 hours after/before waking**

Four subjects (Subject1, 5, 6, and 7) showed the rapid increase of LF/HF ration immediately after waking. LF/HF ratio was shown in red line, and the indoor temperature of living room (0.1m height), bedroom (1.1m height) and dressing room (1.1m height) was shown in orange, grey and yellow line, respectively. Blue marker was defined to show +2SD for distribution within an individual in LF/HF calculated every 10 seconds. Pink marker indicates the sleeping time and black arrow indicates the waking time.

### **Supplementary Figure legend**

#### **Supplementary Figure 1**

##### **Continuous monitoring of LF/HF ratio (sympathetic nerve system)**

Subjects (1-4) stayed at their homes for two days and then stayed at the model house for two days, and the subject (5-8) stayed in the opposite order. LF/HF ratio was shown in red line. Blue marker was defined to show +2SD for distribution within an individual in LF/HF calculated every 10 seconds. Pink marker indicates the sleeping duration time and yellow marker indicates the bath time.

#### **Supplementary Figure 2**

##### **LF/HF ratio (sympathetic nerve system) and HF during during the nighttime**

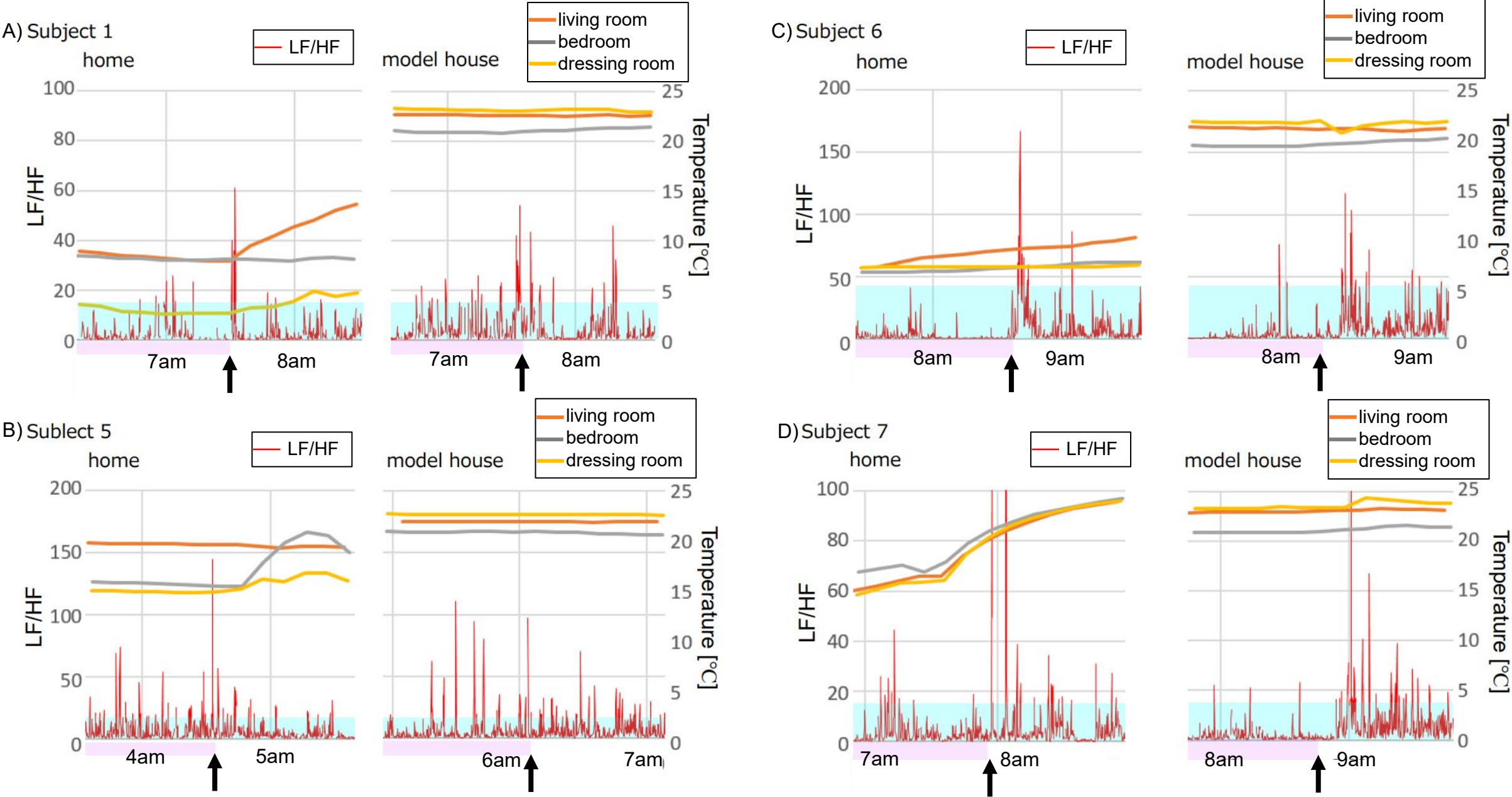
The LF/HF ratio (red line) and HF (blue line) was shown in four subjects (Subject1, 5, 6, and 7) during the nighttime. LF/HF ratio was shown in red line, and pink line indicates the sleeping time.

### **Supplementary Figure 3**

#### **The actigraph to show the physical activity during 2 hours after/before waking**

The actigraph was shown in four subjects (Subject1, 5, 6, and 7), who showed the rapid increase of LF/HF ratio immediately after waking. LF/HF ratio in Figure 1. There was no great physical activity immediately after waking. Pink marker indicates the sleeping time.

Figure



**Table 1** Sleeping duration and frequency domain analysis of heart rate variability signals for 24 hours at the second day

Age, Gender, height/weight/BMI			sleep duration	HR(bpm)	HF(ms <sup>2</sup> )	LF/HF	CVRR(%)
Current disease (drug)							
1.56M	170cm /90kg /31.1	(home)	6 hour 17 minutes	63±12	312±298	2.8±2.0	3.3±0.9
	none	(model house)	7 hour 53 minutes	63±9	347±378	2.9±2.1	3.4±0.9
2. 51F	163cm /56kg /21.1	(home)	(not available)	74±15	453±320	2.0±1.5	4.3±1.1
	anemia	(model house)	6 hour 32 minutes	71±13	365±238	2.1±1.4	4.1±1.1
3. 53F	162cm /60kg /22.9	(home)	5 hour 2 minutes	63±8	429±347	1.5±1.3	3.3±0.7
	none	(model house)	7 hour 7 minutes	66±8	490±388	1.3±1.2	3.5±0.9
4. 77F	150cm /53kg /23.6	(home)	7 hour 26 minutes	63±6	423±291	1.0±0.8	3.4±0.9
	HT (ARB)	(model house)	8 hour 39 minutes	69±9	234±164	1.5±1.1	3.0±0.9
5. 63M	178cm /77kg /24.3	(home)	5 hour 50 minutes	86±10	58±69	4.0±3.2	2.4±0.8
	HT(CCB+ARB)	(model house)	6 hour 42 minutes	87±7	48±64	3.7±3.2	2.2±0.7
6. 33M	177cm /83kg /26.5	(home)	5 hour 50 minutes	74±12	192±211	7.5±7.1	3.8±1.2
	none	(model house)	9 hour 4 minutes	77±14	165±198	9.6±9.4	3.8±1.2
7. 29M	174cm /68kg /22.5	*(home)	5 hour 40 minutes	80±20	449±300	2.6±2.0	4.8±1.8
	Crohn's disease	*(model house)	7 hour 44 minutes	80±20	308±321	3.4±2.6	3.9±1.0
8. 30F	157cm /49kg /19.9	* <sup>†</sup> (home)	6 hour 13 minutes	67±15	1220±951	1.9±1.9	5.5±1.3
	none	*(model house)	7 hour 2 minutes	75±18	760±659	1.7±1.9	4.6±1.1

HR: heart rate, HF: absolute power of high frequency band, LF/HF: ratio of LF (low frequency) band power to HF band power,



HT: hypertension, ARB: angiotensin receptor blockade, CCB: calcium channel blockade

\*The results were obtained for 12 hours due at the second day. <sup>†</sup>The results were obtained at the first day.

Supplement Figure 1

Subject 1



Supplement Figure 1

Subject 2



Supplement Figure 1

Subject 3



Supplement Figure 1

Subject 4





Supplement Figure 1

Subject 5



Supplement Figure 1

Subject 6



Supplement Figure 1

Subject 7





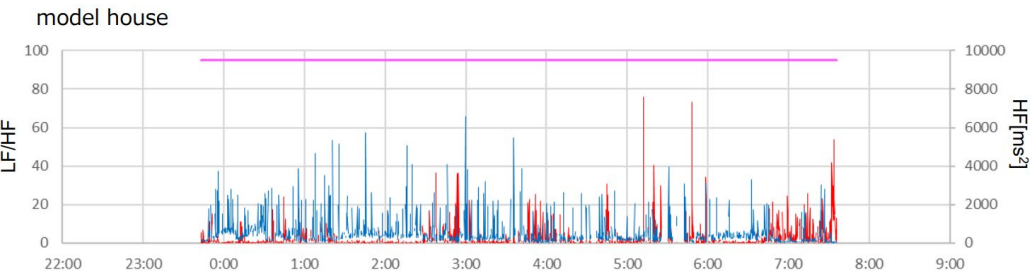
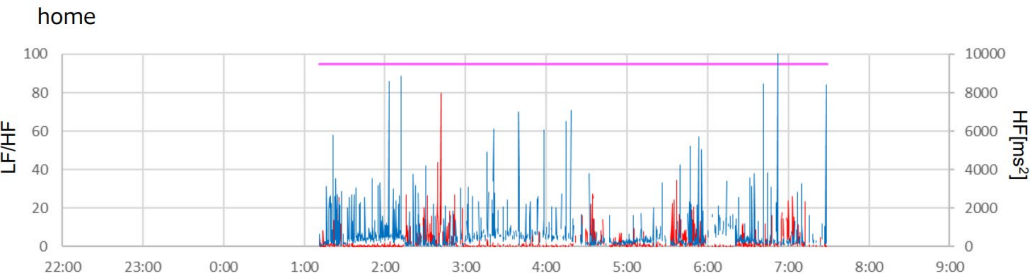
Supplement Figure 1

Subject 8

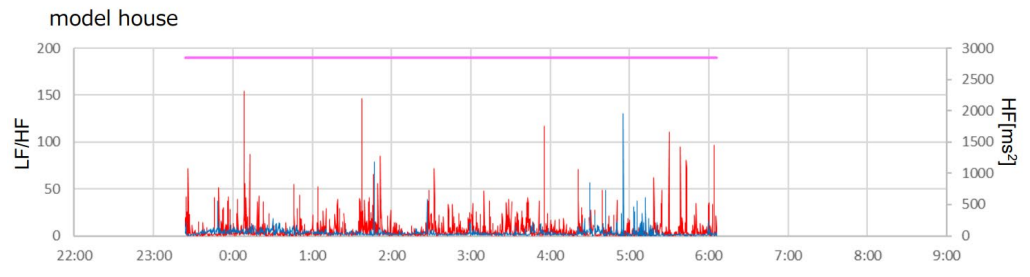
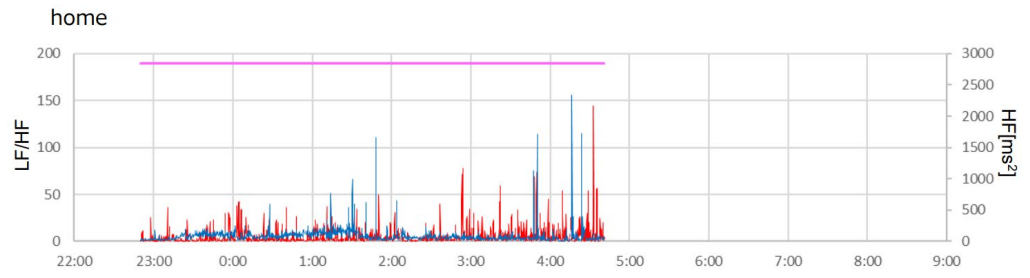


Supplement Figure 2

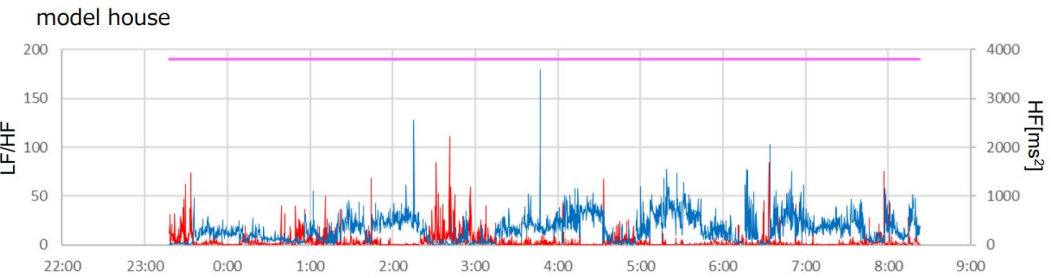
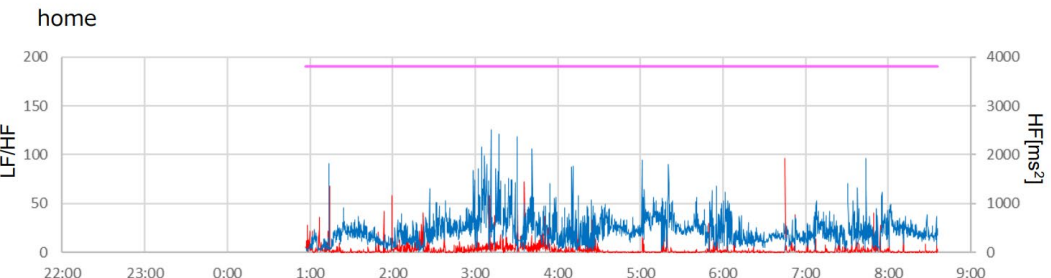
Subject 1



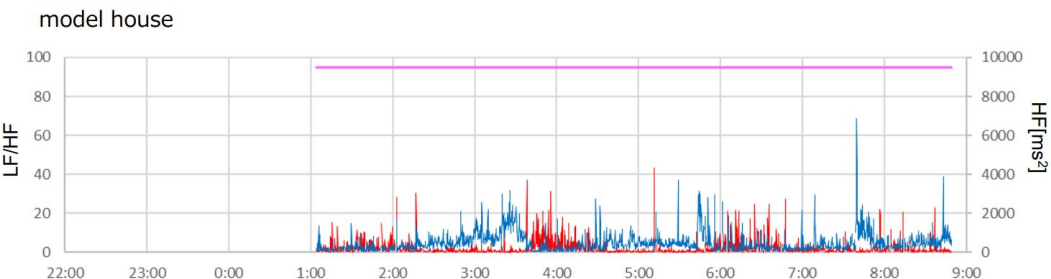
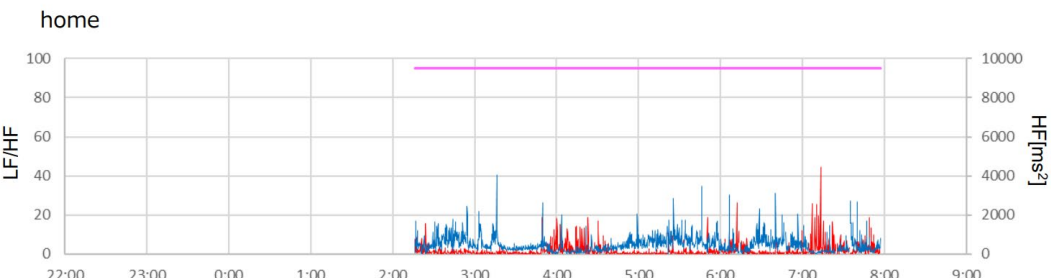
Subject 5



Subject 6



Subject 7



Supplement Figure 3

