

# Utilizing Airflow from Air Conditioners for a Refreshing Awakening during Summer Sleep

Hyojin Jeon<sup>1</sup>, Chungyoon Chun<sup>1\*</sup>

<sup>1</sup> Department of Interior Architecture and Built Environment, Yonsei University, Seoul, Korea

\*Corresponding email: [chun@yonsei.ac.kr](mailto:chun@yonsei.ac.kr)

## SUMMARY

This study aimed to investigate the physiological and psychological effects of three different airflow conditions on occupants' alertness levels and determine the appropriate airflow that induces rapid awakening during summer sleep. The results showed that when airflow with regular fluctuations was directed towards the human body, the total oxygen hemoglobin increased, resulting in brain activation. Additionally, waking up under fluctuating wind led to a higher level of LF/HF, indicating activation of the sympathetic nervous system. Consequently, the subjects' sleep stages gradually became shallower, approaching the wake stage. Subjective responses from participants showed that fluctuating wind received high scores on self-awareness productivity and self-alertness, among others. Importantly, self-awareness and self-alertness were significantly higher in the fluctuating airflow condition than in the other conditions. Based on these results, we conclude that fluctuating airflow stimulation is effective in inducing refreshing awakening during later stages of sleep.

## KEYWORDS

Sleep, Alertness, Airflow, Air-conditioner, Brain blood flow, Heart rate variability, Leeds sleep evaluation questionnaire,

## 1 INTRODUCTION

Human sleep quality is affected by various indoor environmental factors. In Korea, during the summer, where tropical night phenomena occur frequently, occupant's sleep patterns can be further deteriorated due to high temperatures and humidity. It is essential to operate air conditioners to remove the heat load from the bedroom in summer. While there have been numerous studies on suitable room temperatures for good sleep, there is little research on good awakening. It is important to have deep sleep during sleep but supporting a refreshing awakening is also important for improving overall sleep quality. In this context, this study investigated a method to help promote a refreshing awakening during the summer by utilizing the airflow of an air conditioner.

## 2 MATERIALS/METHODS

### Experimental environment

The experiment was conducted in a climate chamber(4.5m(w) x 7.5m(d) x 2.3m(h)). The initial chamber environment was set to a temperature of 29°C and a relative humidity of 65%±5%, which realizes the bedroom thermal environment on summery night (Kim et al, 2010). In this initial environment, the subjects were uniformly stabilized by waiting for 20 minutes. Then, the bed was placed directly under the ceiling air conditioner, and the subjects slept for 15 minutes of sleep under an air conditioner operating at 24°C. Afterward, the temperature was raised to 26°C, and the vane angle of air conditioner was adjusted so that

airflow did not touch the body. Ten minutes before wake-up, airflow for each condition is sent to human.

The airflow conditions were selected based on a pilot test, and the experimental details are presented in Table 1. Case 1 is a condition that transmits airflow with constant fluctuations to the human body, Case 2 continuously delivers airflow to the human body without fluctuation, and Case 3 is an insensitive airflow of 0.15 m/s or less that hardly touches the sleeping human (Table 1). All subjects experienced all three conditions and were asked to take a 90-minute nap.

Table 1. Experimental Conditions.

	Airflow Condition	Temperature Condition	Airflow Condition	Temperature Condition
	0~80min		80~90min	
Case 1	Indirect wind	24°C	Fluctuating wind	26°C
Case 2	Indirect wind	24°C	Direct wind	26°C
Case 3	Indirect wind	24°C	Indirect wind	26°C

### Characteristics of participants

Eight college students (four males and four females), who reported no sleep disorder, participated in all three experimental conditions. They were asked to wear same clothes (underwear, short pajamas top and bottom) and quilts (M1+B, percentage coverage of body surface area : 67% by Lin et al.(2008)). The overall thermal resistance was the sum of both bedding and clothing insulation (1.85 clo). Alcohol, caffeine, and intense physical activity were forbidden prior to the experiment. Furthermore, they participated in experiment at the same time for three whole days.

### Measurements

Physiological alertness was assessed using measures of cerebral blood flow and heart rate variability. For cerebral blood flow, changes in the concentration of total oxygenated hemoglobin were measured using Functioning Near-Infrared Spectroscopy (fNIRS, HOT-2000, Japan). When the human brain is activated, it requires more glucose and oxygen, which are supplied by blood vessels, leading to an increase in the concentration of oxygenated hemoglobin in the bloodstream of the cerebral cortex. Because fNIRS is sensitive to hair, measurements were taken on hairless forehead, corresponding to the frontal cortex area. Given the relevance of the prefrontal cortex in cognitive functions, cerebral blood flow was measured and compared during N-back task (Millisecond Software, US), the task-based cognitive function test.

Spectral analysis of heart rate variability (HRV) during a nap was performed on eight healthy adult subjects. They were each attached to an electrocardiogram (ECG) sensor (Intercross 413, Japan) on three different locations: a reference, under collarbone and on rib. The subjects were instructed to rest quietly for 20 minutes before the recording began to establish a baseline HRV. The analysis of HRV in the frequency domain is vulnerable to movement artifacts, which can affect the accuracy of the results. To minimize these artifacts, the subjects were asked to remain still during the recording, and the average values for five minutes were calculated. The average of five minutes before and after airflow stimulation was compared to investigate changes in HRV in response to sleep stage. The measurements proposed in this paper include the low frequency and high frequency power, as well as the ratio of Low Frequency / High Frequency.

Heart rate variability is controlled by united effects of the sympathetic and parasympathetic nervous system (Stein, P. K et al. 2012). The high frequency (HF) power reflects parasympathetic nervous system activity, while the low frequency (LF) power is associated with a combination of sympathetic and parasympathetic. The LF/HF ratio is a measure of sympathovagal balance and can provide insight into the autonomic regulation of the cardiovascular system. Main parameters of frequency domain (LF, HF, LF/HF) are deeply related to sleep. For example, the level of HF increases to a peak in slow wave sleep and it gradually decreases at the low sleep stages (stage 1 or 2). In contrast, LF during REM sleep significantly increases with the LF/HF ratio. These findings suggest that HRV and its frequency domain parameters are strongly influenced by the sleep-wake cycle.

In this study, to evaluate psychological awakening, the Leeds Sleep Evaluation Questionnaire (LSEQ) scale developed by Choi et al. (2012) for Korea was used. The LSEQ consists of ten questions, and only two questions in the behavior after waking up (number 6 and 7) area were extracted for this study. Additionally, self-awareness productivity and self-awareness alertness were collected to investigate the subject's alertness after waking up. To measure self-awareness productivity, a visual analog scale ranging from 'Very high than usual' to 'Very low than usual' at both ends (McCartney, K. J. et al. 2002). For self-awareness alertness, a visual analog scale ranging from 'Extremely alert' to 'Extremely sleepy, can't keep awake' was used at both ends (Kaida, K. et al. 2006).

The use of the LSEQ scale and visual analog scales allowed us to obtain a more detailed assessment of psychological awakening. Measuring the subjects' responses to different levels of airflow during sleep provides valuable information about their level of alertness and productivity upon waking up, contributing to a better understanding the impact of airflow on daily activities and work performance.

### Experimental procedures

The subjects entered the preconditioned chamber and attached a heart rate variability sensor. After sitting in their chairs and waiting for 20 minutes to stabilize their thermal state, they moved to a bed where an air conditioner was turned on to facilitate sleep. Over the course of 90-minutes, the temperature was adjusted, with the initial 15 minutes operating at 24°C and the subsequent 65 minutes at 26°C. Airflow characteristics were adjusted to create a subtle(indirect) airflow that did not directly touch their bodies for 80 minutes. During the last 10 minutes before waking up, the airflow was changed to provide the subjects with different airflow conditions for awakening. After waking up, the subjects completed a subjective response questionnaire, and brain blood flow was measured using the fNIRS during the cognitive function test (N-back).

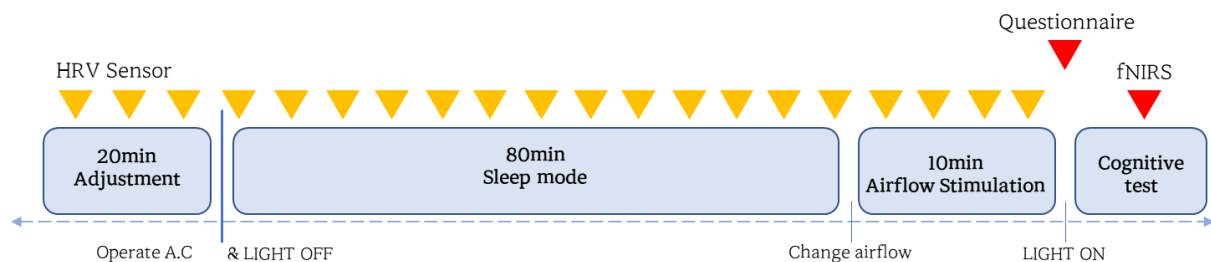


Figure 1. Timeline of the experiments.

### Analysis method

The data were analyzed using the statistical analysis program IBM SPSS Statistics version 26. First, normality test was conducted on brain blood flow data based on the subject airflow conditions. Then, one-way ANOVA was performed to examine whether there was a difference in the amount of change in total oxygen hemoglobin between the three airflow conditions ( $p=0.001$ ). The Tukey HSD method was used for post-hoc comparisons. Heart rate variability was analyzed using paired-sample t-tests based on the three airflow conditions. In addition, subjective responses were analyzed using the Friedman test.

### 3 RESULTS

In this study, we analyzed and presented the results of brain blood flow, heart rate variability, and subjective response measurements that were obtained during the experiment.

#### The change in total hemoglobin concentration

After analyzing the trend of the total hemoglobin concentration over time for each subject, it was observed that the concentration increased sharply compared to the rest period at the start of the test (see Figure 2).

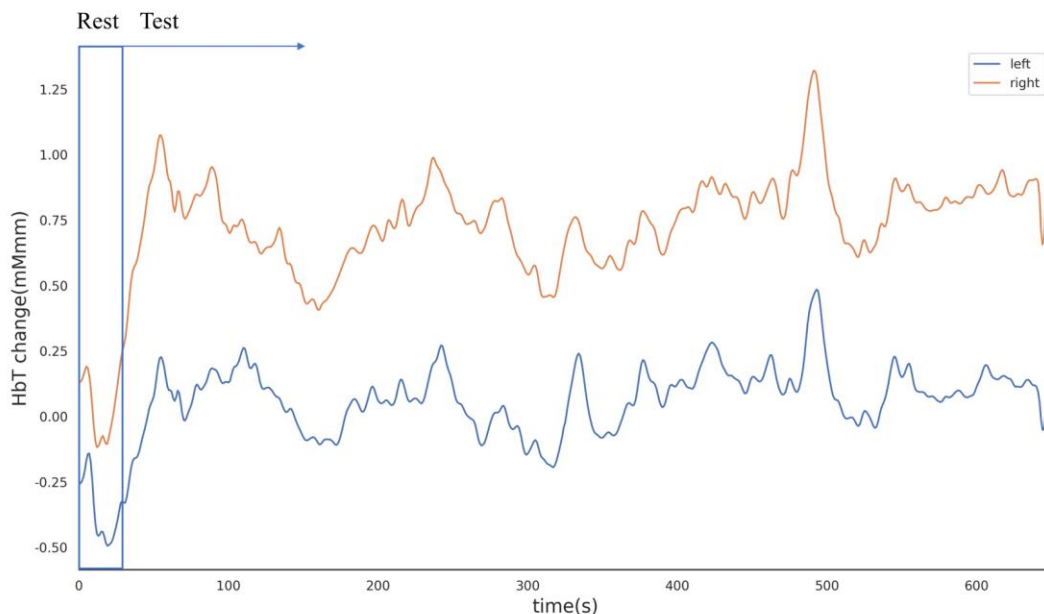


Figure 2. Examples of changes in total hemoglobin (HbT) over time in a male subject.

To assess the normality of the data, Shapiro-Wilk's test was conducted for the total amount of hemoglobin change for each airflow condition, and it was found that the data followed a normal distribution. The Bartlett test was performed to test for the equality of variances, and all data were confirmed to have equal variance. To determine whether there were any significant differences in total hemoglobin concentration among the three airflow conditions, a one-way ANOVA was conducted. The results indicated a significant difference ( $p < 0.001$ ) in the total hemoglobin concentration change across the conditions. Specifically, the total hemoglobin change in Case 1 was found to be greater than that of the other conditions, indicating that the brain was most activated when a fluctuating airflow touched the human body.

To further investigate the differences between the groups, a post-hoc test using the Turkey HSD method was performed. The results indicated that there were statistically significant differences between the three conditions ( $p < 0.001$ ). The findings suggest that the brain's sensory cortex is more strongly activated by a fluctuating airflow compared to steady(direct) or subtle(indirect) airflow conditions.

Table 2. One-way ANOVA and Tukey HSD test between total hemoglobin change under three conditions.

Condition	One-way Anova		Tukey HSD
	F	p-value	
Case 1	275.484	<b>0.001</b>	2 3 ***
Case 2			1 3 ***
Case 3			1 2 ***

### Heart rate variability

During each session, HRV data were collected and the average data for 5 minutes after airflow stimulation were analyzed. To ensure the accuracy of the data, artifacts caused by tossing and turning during sleep were removed. A paired t-test was conducted to examine the effect of airflow conditions on HRV measures, and the HRV data were compared among the three different airflow conditions (Case 1, Case 2, and Case 3).

After conducting a paired t-test, the results showed that two indicators, LF and LF/HF, differed significantly between Case 1 (fluctuating wind) and Case 3 (Figure 3). Specifically, the LF power was found to be highest in Case 1, followed by Case 2 and then Case 3, indicating that the sympathetic nervous system was most active in Case 1 compared to the other conditions. On the other hand, no significant differences were observed in the HF power among the three conditions. Moreover, the LF/HF ratio showed the highest median value in Case 1, followed by Case 2 and then Case 3, suggesting a greater activation of the sympathetic nervous system compared to the parasympathetic nervous system.

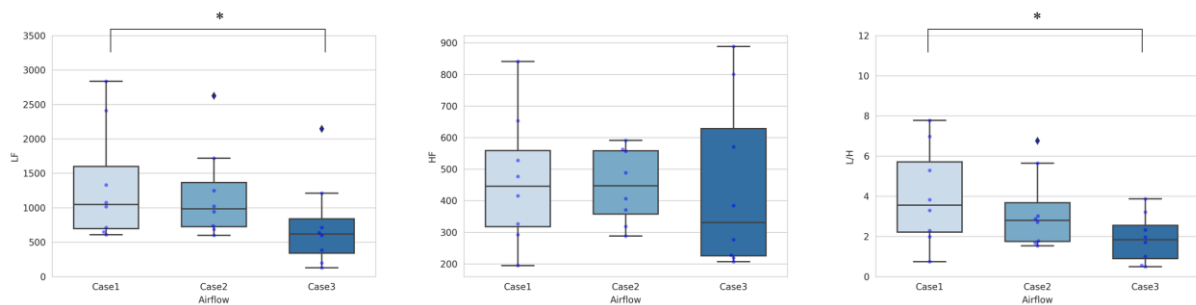


Figure 3. Difference in low frequency, high frequency, low frequency/high frequency assessed in the three airflow conditions(boxplot and scatter plot).

Table 3. Friedman test and Conover test between low frequency, high frequency, low frequency/high frequency under three conditions.

		t value	p-value
LF	Case 1 vs Case 2	0.450	0.668
	Case 1 vs Case 3	-2.814	<b>0.026*</b>
	Case 2 vs Case 3	-2.080	0.083
HF	Case 1 vs Case 2	0.442	0.674
	Case 1 vs Case 3	-.159	0.878
	Case 2 vs Case 3	-.021	0.984

LF/HF	Case 1 vs Case 2	0.926	0.390
	Case 1 vs Case 3	-2.894	<b>0.023*</b>
	Case 2 vs Case 3	-1.396	0.212

\*p<0.05

### Subjective response

Self-awareness productivity and self-awareness alertness were recorded and used for analysis.

For the analysis of the responses to the LSEQ 6 and 7, the average value for each condition was calculated. All response data were analyzed using the Friedman test.

Regarding self-productivity, the highest score of 0.54 was observed in Case 1, but no statistically significant difference was found between this condition and the others. Concerning self-awareness alertness, participants reported a mean score of 0.59 out of 1 in Case 1, which is closer to 'Extremely alert' compared to the other conditions ( $\chi^2 = 7.75$ ,  $p=0.02$ ). They felt more alert when waking up through the fluctuating airflow than in the other conditions.

In the LSEQ 6, participants reported feeling more comfortable when awakening under the indirect airflow condition of Case 3 compared to the other conditions. In the LSEQ 7, participants required a longer period to fully wake up in Case 1 compared to the other conditions.

Table 4. The results of subjective responses for each condition (Self-awareness productivity, Self-awareness alertness, LSEQ 6, LSEQ 7).

		Mean	Friedman test		Conover
			Chi square( $\chi^2$ )	p-value	
Self-awareness productivity	Case 1	0.541428	3.25	0.19	
	Case 2	0.420181			
	Case 3	0.471243			
Self-awareness alertness	Case 1	0.594324	7.75	<b>0.02*</b>	Case 1 & Case 2
	Case 2	0.398557			
	Case 3	0.490627			
LSEQ 6	Case 1	56.25	0.27	0.87	
	Case 2	60			
	Case 3	87.5			
LSEQ 7	Case 1	82.5	0.26	0.87	
	Case 2	80			
	Case 3	73.75			

\*p<0.05

## 4 DISCUSSION & CONCLUSIONS

This study aimed to investigate the effects of three different air conditioning airflow conditions on subjects' alertness. After 90 minutes of nap, the subjects were exposed to airflow for the last 10 minutes, and their degree of awakening was evaluated.

The results of cerebral blood flow showed that the frontal cerebral cortex was more active when subjects woke up from fluctuating airflow. Subjects tended to wake up faster when irregular airflow was transmitted to the face, trunk, and feet. This could be because irregular airflow produces a stronger sense of airflow than indirect or constant airflow. Additionally, heart rate variability results showed that fluctuating airflow induced activation of the sympathetic nervous system, which suggests that it may affect the transition from NREM to

REM sleep. It is possible that the increased sympathetic activity associated with fluctuating airflow may contribute to a more abrupt transition from NREM to REM sleep, resulting in faster awakening. However, further research is needed to explore the specific mechanisms underlying these effects and to determine whether the observed changes in autonomic nervous system translate into measurable differences in sleep process.

The study found a difference in self-awareness alertness among occupants based on the type of airflow, but no significant difference was observed in LSEQ questions 6 and 7 and self-awareness productivity. The highest self-awareness alertness and productivity were observed in Case 1. In LSEQ question 6, the highest score was 82.5 points under Case 1 (fluctuating wind), followed by 80 points in Case 2 and 73.75 points in Case 3. For LSEQ question 7, the highest score was 87.5 points under Case 3 (indirect wind) conditions, followed by 81.25 points in Case 1 and 86.25 points in Case 2.

This means that even under the same temperature conditions, the alertness of the occupant may vary depending on the type of air conditioner airflow. Consequently, at the last stage of sleep, airflow caused by fluctuations causes faster awakening and is effective.

According to the results of this study, different airflow conditions may be necessary depending on the sleep stage, and according to the results of this study, a stimulating airflow with fluctuations may be more effective in awakening. The results of this study are consistent with previous findings.

In practical terms, this study can be helpful for people who have difficulty waking up. Overall, the study provides new insights into the relationship between airflow condition and brain activation and highlights the potential importance of sensory input in modulating cortical activity. This seems to be applicable to some people. Some people have difficulty getting out of the transitional state between sleep and awakening in the morning (Trotti, L. M, 2017). If this condition persists for several minutes to several hours, it interferes with daily life and affects daytime life due to reduced performance and reduced alertness. Such an airflow solution can be effective in waking humans in a sleep inertial state. However, since the impact of airflow on sleep stages is not well understood, further research is needed.

## **5 REFERENCES**

- Choi, H. and Kim S. 2012. Korean versions of self-reported sleep questionnaires for research and practice on sleep disturbance. *Korean J Rehabil Nurs*, 15, 1-10.
- Kim, D., Kum, J., and Park, J. 2006. Evaluation of thermal comfort during sleeping in summer-part II: about mean skin temperatures and physiological signals. *Korean Journal of Air-Conditioning and Refrigeration Engineering*, 18(1), 1-6.
- Kim, M., Chun, C., and Han, J. 2010. A study on bedroom environment and sleep quality in Korea. *Indoor and Built Environment*, 19(1), 123-128.
- Kaida, K., Takahashi, M., et al. 2006. Validation of the Karolinska sleepiness scale against performance and EEG variables. *Clinical Neurophysiology*, 117(7), 1574-1581.
- Lin, Z. and Deng, S. 2008. A study on the thermal comfort in sleeping environments in the subtropics—Measuring the total insulation values for the bedding systems commonly used in the subtropics. *Building and Environment*, 43(5), 905-916.
- McCartney, K. J. and Humphreys, M. A. 2002. Thermal comfort and productivity. *Proceedings of Indoor Air*, 2002, 822-827.
- Okamoto-Mizuno, K., Tsuzuki, K., Mizuno, K., and Iwaki, T. 2005. Effects of partial humid heat exposure during different segments of sleep on human sleep stages and body temperature. *Physiology & behavior*, 83(5), 759-765.

- Stein, P. K. and Pu, Y. 2012. Heart rate variability, sleep and sleep disorders. *Sleep medicine reviews*, 16(1), 47-66.
- Teramoto, Y., Tokura, H., Ioki, I., et al. 1998. The effect of room temperature on rectal temperature during night sleep. *Journal of thermal biology*, 23(1), 15-21.
- Togo, F., Aizawa, S., Arai, J. I., et al. 2007. Influence on human sleep patterns of lowering and delaying the minimum core body temperature by slow changes in the thermal environment. *Sleep*, 30(6), 797-802.
- Trotti, L. M. 2017. Waking up is the hardest thing I do all day: sleep inertia and sleep drunkenness. *Sleep medicine reviews*, 35, 76-84.