# Method design of interactive digital devices to support the workspace comfort

Athifa Sri Ismiranti [a,1*], Akhmadi [a,2], Arini Arumsari [a,3], Mahendra Nur Hadiansyah [a,4], Alfito Aji Denandra [a,5], Sarah Nurul Azizah [a,6]

[a] Telkom University, Jl. Telekomunikasi. 1, Terusan Buahbatu - Bojongsoang, Bandung 40257, Indonesia
[1] athifaismiranti@telkomuniversity.ac.id *; [2] akhmadi@telkomuniversity.ac.id; [3] ariniarumsari@telkomuniversity.ac.id; [4] mahendrainterior@telkomuniversity.ac.id; [5] alfitoajidenandra@student.telkomuniversity.ac.id; [6] sarahnrll@student.telkomuniversity.ac.id
* corresponding author

ARTICLE INFO

**Article history**
Received 2023-09-14
Revised 2023-10-22
Accepted 2023-11-26

**Keywords**
Workspace;
Comfort;
Flexibility;
Interactive Digital Device;
Arduino.

ABSTRACT

There are many alterations and adaptations of the workspaces after the Covid-19 pandemic. Nowadays, workspaces are required to have flexibility in facilitating physical and virtual activities, work-from-home (WFH), and work-from-office (WFO) activities. Besides, workspaces must provide comfort based on user preferences and demand to support workers' health and productivity. In order to answer these problems, the design of interactive digital devices that can be adjusted according to physical needs, activities, and preferences is needed to support the ideal workspace comfort. The research method used in this research is a literature review related to ideal workspace comfort standards and an assessment of the Arduino as an interactive digital device to produce an interactive digital device method design that can detect ideal comfort and be applied to workspaces. The result shows that as an interactive digital device, Arduino can be implemented in a workspace to detect and produce ideal workspace comfort regarding lighting, noise, temperature, and humidity. Arduino also supports flexibility and varied demand in a workspace because of its adjustable artificial intelligence feature. The ideal standard of workspace differs based on the activities and geographical conditions of the country and is related to the varied preferences of its users. Based on its complexity, for further research to be carried out, it is recommended to conduct a case study of ideal workspace interior design with an Arduino device in a specific place to generate more accurate data and suitable workspace design.



## 1. Introduction

After the Covid-19 pandemic, work activities and workplace locations have changed significantly. Nowadays, workspaces are required to have flexibility in facilitating physical and virtual activities, work-from-home (WFH), and work-from-office (WFO) activities. This phenomenon gives the workplace or workspace a new definition and function: a flexible and adaptable space with each user's preferences [1]. The ideal comfort of a healthy workspace interior that can support productivity is determined by several aspects, namely the level of lighting, noise, temperature, temperature or air circulation, and humidity [2]–[4]. Space optimisation, colour determination, and flow in space affect the health environment and can help reduce workers' stress [5]. Based on Bergefurt *et al.* [6], factors that affect work comfort are noise level, temperature, space circulation, level of privacy, the flexibility of furniture, colour of space, and cleanliness of the workspace. In addition, personal characteristics also affect the level of stress and distraction at work. The results of their study stated that noise level and personal character are the main factors that can affect work productivity, either on a work-from-home (WFH) or work-from-office (WFO) basis.

They suggested the concept of flexible work areas that can facilitate workers in choosing places and conditions to support work comfort preferences. According to Shin [7], each person's assumptions and preferences are related to the same physical environment; therefore, environmental conditions are needed that can be studied and explored more than just the physical setting design. A post-pandemic phenomenon is flexible comfort based on preferences, physical conditions of the environment, and user needs to increase productivity at work. The need for flexibility in the workspace makes an ideal comfort that needs to be adjusted to the preferences and needs of the user. The comfort factor detection tool using interactive digital devices, such as Arduino, Internet of Things, or robotic technology, has been widely applied before, such as Sung and Shih [8] proved Arduino UNO as one of the devices with an IoT system capable of analysing the thermal comfort of indoor areas based on three aspects; comfort, in general, and energy savings. Quintana *et al*. [9] have also successfully studied robotic systems that can detect and evaluate the comfort level of working in the interior based on temperature, humidity, airspeed, lighting, and noise factors. However, the detection in these two studies only discusses detection and analysis, so further studies are needed regarding its implementation in the interior to support human comfort at work.

The Arduino system, as one of the Internet of Things (IoT) based devices itself, has been widely studied and proven regarding its correlation to be applied in the interior of the workspace. For example, a prior study by Gladence *et al.* proved the Fuzzy Logic System with Arduino, which can produce a human tracking system to support the creation of buildings with intelligent systems [10]. The building with an intelligent system in the prior research is the automation of building elements based on human activity, such as turning on the air conditioner automatically based on human activity. The Arduino system also has the potential to be implemented in future office intelligent control lighting as the automatic lighting system [11]. The need for flexibility in the workspace makes an ideal comfort that needs to be adjusted to the preferences and needs of the user. In order to answer these problems, the design of interactive digital devices that can be adjusted according to physical needs, activities, and preferences is needed to support the ideal comfort of the workspace. Furthermore, the Arduino implementation system in the average workspace is still in the process of development. It needs to be studied more deeply from various aspects of human comfort based on various physical environmental factors and the flexibility of the required workspace. Therefore, this research aims to examine the supporting factors of human comfort related to physical environmental factors such as lighting, noise, temperature, and humidity. This research also aims to examine interactive digital device methods using Arduino devices to support human comfort based on these four factors. The review and experiment results will then be analysed to create the design of interactive digital devices to support the ideal comfort of a flexible workspace.

## 2. Method

This research uses mixed methods with the literature review and experiments on interactive digital devices to produce interactive digital device method designs. The research process is by collecting, evaluating, and synthesising relevant literature sources to find research gaps from previous studies that have yet to be answered regarding interactive interiors in the workspace. The interactive digital device used in this research is Arduino. Using a combination of hardware, programming languages, and an integrated development environment (IDE), Arduino is an open-source physical computing platform. Writing programs, converting them to binary code, and putting them into microcontroller memory with an IDE software integrated with Arduino [12]. Arduino can be connected to several sensor devices, such as light sensors (photo sensors), proximity sensors (ultrasonic sensors), humidity sensors, and many more. Primary and secondary data collected in the research process are; (1) Preliminary data related to post-pandemic workplace adaptations and alterations; (2) Ideal comfort of workspace data related to lighting, noise, temperature, and humidity; (3) Arduino sensor data to measure comfort parameters; (4) Arduino experimental, comparison, and simulation data to produce method design of interactive digital devices to support the workspace comfort. The research results used several theoretical references to determine suitability for this study as follows:

- Sustainability and comfort theory "Herzberg's Two-Factor Theory: Theory about motivational factors and obstacles in the work environment that can influence comfort" [13]. The study stated that work has a strong connection with psychology, behaviours, and physical condition. In order to improve workers' motivation at work, the physical environment needs to be considered to enhance workers' moods and support their activities and physical conditions based on their preferences.

- Human interaction approach "The Self-Organization of Human Interaction" [14]. Human interaction is based on human behaviours, memory, cognitive process, coordination, and adaptation, then how these factors can be interrelated. Human interaction is easily adapted and flexible during dynamic settings, under social situations, or under different task conditions. Interaction between humans and space can occur when there is a dynamic setting in space or changes in space elements that occur due to human interaction and activities in it. Dynamic settings in a workspace can trigger human-space interaction and human behaviours alterations.
- The theory of environmental comfort "Toward a theory of environmental satisfaction and human comfort: A process-oriented and contextually sensitive theoretical framework" [7]. The environment has two aspects: social and physical. In an optimal physical environment, there will be satisfaction and comfort for humans in it. Modification of the environment will lead to the adaptation of human behaviour, so efforts are needed to make the environment better and more comfortable for humans, both socially and physically. Therefore, an optimal and comfortable environment for humans requires structural and physical manipulation in order to provide satisfaction and comfort in human activities socially and physically.
- Interactive technology approach "Immersive Interactive Technologies for Positive Change: A Scoping Review and Design Considerations" [15]. Today's technology, especially interactive technology, can provide new experiences for humans. Interactive technology itself is closely related to virtual environments and immersion concepts. This immersion concept can affect psychological immersion and spatial immersion in human cognition. Based on the viewpoint of medicine and psychology, interactive technology should be made affordable and consumer-friendly devices. Interactive technology will have a positive impact on the human body as it will allow exploration and cognitive processes. It is also related to mindfulness, mind-body dialogues, concentration, and attention. Therefore, interactive technologies can have a positive impact on humans physically and psychologically by creating immersive and interactive experiences for humans as long as the technology is affordable and easy to use. Arduino itself is a technology that is easy to use and affordable, so it has a high potential to be used in spaces to support interactive experiences.
- Automation and control approach "The Interaction-Attention Continuum: Considering Various Levels of Human Attention in Interaction Design" [16]. In interactive technology, controlling and automating using sensors is an advantage. However, the control system must be made in such a way as to facilitate the user. For example, the use of lighting control through a smartphone will make it easier for humans to set according to their preferences. However, it can also be burdensome if someone always has to take out the smartphone and use it to adjust the lighting. Based on the results of experiments and exploration in the study, it was found that tangible gesture interaction with various levels of control systems will make it easier for humans to control adjustable systems. The interface in the technology system should also support the user to understand the input and output system easily. In addition, understanding routine activities and human behaviour also needs to be considered in an interactive design. Arduino itself is a system that is easy to understand in terms of input and output and needs to consider the control system and its relation to daily human activities.

The work environment will affect the physical and psychological comfort of its users, so the modification and manipulation of space will result in human behaviour adaptation. Interaction between humans and space can be created through dynamic settings that can be realised through interactive technology. Interactive technology has a positive effect on humans physically and psychologically related to exploration and automation. However, it needs to be affordable, easy to use, easy to operate, facilitate, and support human activities. Arduino, as the device studied in this research, is a technology that is easy to use and affordable, so it has a high potential to be used in spaces to support interactive experiences, Fig. 1 is research flow.

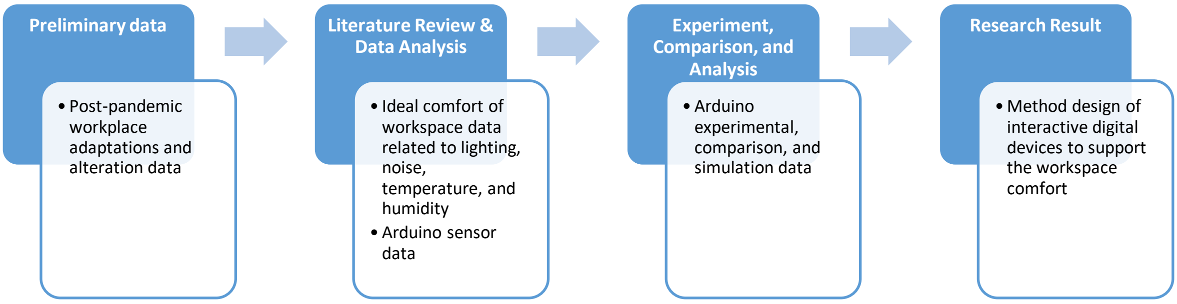


**Fig. 1.**Research flow

# 3. Results and Discussion

## 3.1. Literature Review Results

Based on the literature review results, the data conclusions regarding the ideal comfort of a workspace are obtained as follows. Workspace comfort based on lighting is described in Table 1.

**Table 1.** Workspace Lighting Comfort Standard Data

| Ideal Lighting Levels (lux) | Specifications and Sources | | |
|---|---|---|---|
| | ***Workspace/Activity Specifications*** | ***Source*** | ***Country Source*** |
| 100 | Coarse and intermittent work; storage room/equipment; continuous work | (Minister of Health Decree Number 1405/MENKES/SK/XI/2002) [17] | Indonesia |
| 200 | Manual and continuous work; machining and rough assembly work | | |
| 300 | Routine work: administration room, control room, machining, and assembly work | | |
| 500 | The work is rather delicate: drawing, working with office machines, inspection | | |
| 300 | Standard workspace | (Regulation of the Minister of Health of the Republic of Indonesia Number 48 Year 2016 on Occupational Safety and Health Standards) [18] | Indonesia |
| 100 - 200 | Standard workspace | (Regulation of the Minister of Labor (PMP) Number 7 Year 1964) [19] | Indonesia |
| 300 | Computer-based work | [20] | United Kingdom |
| max 500 | Paper-based work | | |
| 300 - 500 | | | North America |
| 320 | Routine office work | | Australia & New Zealand |
| 350 | Standard workspace | (SNI 16-7062-2004) [21] | Indonesia |
| 350 | Director's room, workspace, computer room | (SNI-03-6197-2000) [22] | Indonesia |
| 300 | Meeting room | | |
| 750 | Drawing room | | |
| 100-150 | Working areas where visual tasks are only occasionally performed | [23] | The United Arab Emirates (UAE) |
| 250 | Easy office work | | |
| 500 | Standard office work, PC work, study library | | |
| 750 | mechanical workshops, office landscapes | | |
| 1000 | Standard drawing work, detailed mechanical workshops | | |

| Ideal Lighting Levels (lux) | Specifications and Sources | | |
|---|---|---|---|
| | ***Workspace/Activity Specifications*** | ***Source*** | ***Country Source*** |
| 1500 - 2000 | Detailed drawing work, very detailed mechanical works, electronic workshops, testing | | |
| 500 | writing, reading, and typing work | [24] | Tanzania |

a. The ideal standard range (standard workspace) is 100 - 500 lux.

Based on the data in Table 1, it is found that the ideal standard of workspace comfort based on lighting is varied and relative to the type of work activity in it and based on the existing conditions of the geographical environment. For example, lighting standards in Indonesia are different from those in The United Arab Emirates (UAE). However, based on the results of a study of eight journals that reviewed lighting standards in seven different countries, it was found that the average journal stated that the ideal lighting level in the standard workspace is 100 - 500 lux. Based on the literature reviews of six journals that examined eight different countries, it was found that the ideal standard of workspace comfort based on noise level is varied and relative to the type and duration of work activities in it. Four out of eight countries studies stated that the maximum noise level in the workspace is 85 dB, and the range of noise level for standard workspace based on the eight countries studied is -5 - 135 dB, depending on the type of activities conducted. So, the ideal noise level in the workspace for standard work activities is 10 - 85 dB (Table 2).

**Table 2.** Workspace Noise Comfort Standard Data

| Ideal Noise Levels (dB) | Specifications and Sources | | |
|---|---|---|---|
| | ***Workspace/Activity Specifications*** | ***Source*** | ***Country Source*** |
| -5 | Private workspace | (ISO 3382-3, 2012), [25] | Iran |
| 10 - 15 | Standard workspace | | |
| <55 | Standard workspace | [26] | Sweden |
| 85 | Continuous working time not more than 8 hours/day or 40 hours a week | (Minister of Manpower Decree Number 51/MEN/1999), (WHS, 1993), (ACGIH, 1991) [19] | Indonesia |
| | | | Australia |
| | | | United States of America |
| 85 | 8 hours of daily exposure | (Minister of Environment Decree Number 48 Year 1996) [17] | Indonesia |
| 88 | 4 hours of daily exposure | | |
| 91 | 2 hours of daily exposure | | |
| 94 | 1-hour of daily exposure | | |
| 97 | 30 minutes daily exposure | | |
| 100 | 15 minutes daily exposure | | |
| <85 | Daily exposure > 4 hours | [27] | Spain |
| 80 - 135 | Daily exposure limit | [28] | Slovenia |

b. The ideal standard range (standard workspace) is 10 - 85 dB.

Based on the data in Table 3, the ideal standard of workspace comfort based on thermal tends to be similar. Table 3 states studies from nine different sources that examined eight different countries. The Table 3 shows that the ideal thermal level in a standard workspace is 293 - 301.5 K or about 20 – 27 °C, but the ideal temperature to increase work productivity is 293 - 295.5 K or about 20 – 24 °C [29].

**Table 3.** Workspace Thermal Comfort Standard Data

| Ideal Thermal Level (Kelvin) | Specifications and Sources | | |
|---|---|---|---|
| | ***Workspace/Activity Specifications*** | ***Source*** | ***Country Source*** |
| 295 - 299 | Standard workspace | (HEALTH CENTER, 1995) [19] | Indonesia |
| 297 | Standard workspace | [17] | Indonesia |
| 297- 300 | Standard workspace | [30] | Singapore |
| 298 | Standard workspace | [31] | Japan |
| 294 - 298 | Standard workspace | [6] | Netherlands |
| 293 - 297 | Warm period | (EN ISO 7730, 2006) [26] | Sweden |
| 296 - 299 | Cool period | | |
| 293 - 295.5 | Increased productivity | [26] | |
| 293 - 298 | Standard workspace | [32] | Chile |
| 295 | Standard workspace | [33] | China |
| 293 - 299 | Standard workspace | [34] | United States of America |

[c.] The ideal standard range (standard workspace) is 293 - 301.5 K.

The results of the literature reviews related to workspace humidity comfort standards were not easily found. Found three journals that examine four different countries related to humidity comfort in the workspace. In conclusion, the ideal humidity level in the workspace is 300000 - 700000 g/m3, but the ideal humidity for a two-season (tropical) country like Indonesia is 400000 - 500000 g/m3 (Table 4). The results of literature reviews related to ideal comfort workspace based on lighting and noise are varied and relative to the type of work activity, duration of work, and the existing conditions of the geographical environment. To conclude, the ideal lighting level in the standard workspace is 100 - 500 lux, and the ideal noise level in the workspace for standard work activities is 10 - 85 dB. The ideal comfort workspace based on thermal tends to be similar. The results show that the ideal thermal level in a standard workspace is 293 - 301.5 K or about 20 – 27 °C but the ideal temperature to increase work productivity is 293 - 295.5 K or about 20 – 24 °C [29]. The ideal humidity level in the workspace is 300000 - 700000 g/m3 for subtropical countries and the ideal humidity for a two-season (tropical) country like Indonesia is 400000 - 500000 g/m3.

**Table 4.** Workspace Humidity Comfort Standard Data

| Ideal Humidity Level (g/m3) | Specifications and Sources | | |
|---|---|---|---|
| | ***Workspace/Activity Specifications*** | ***Source*** | ***Country Source*** |
| 400000 - 500000 | Two-season (tropical) country | (WHS, 1992) [19] | Australia |
| | | | Indonesia |
| 300000 - 700000 | Relative humidity | (EN ISO 7730, 2006) [26] | Sweden |
| 690000 | Ideal work area | | |
| 300000 - 600000 | Standard workspace | ASHRAE 55-1989 [35] | United States of America |

[d.] The ideal standard range (standard workspace in tropical countries) is 400000 - 500000 g/m3

## 3.2. Arduino Experiment Results

Experiments and assessments of interactive digital devices using Arduino and its components were carried out to obtain primary data. The sensors used are Light Dependent Resistor (LDR) for lighting sensors, KY-038 sound sensors for detecting noise levels, a KY-028 temperature sensor to detect temperature levels based on thermistor resistance, and a humidity sensor in the form of a DHT-11 sensor. The Arduino output data studied are kinetic data (servo and stepper motors) and lighting (LED), Fig. 2 is the Arduino experiment documentation.

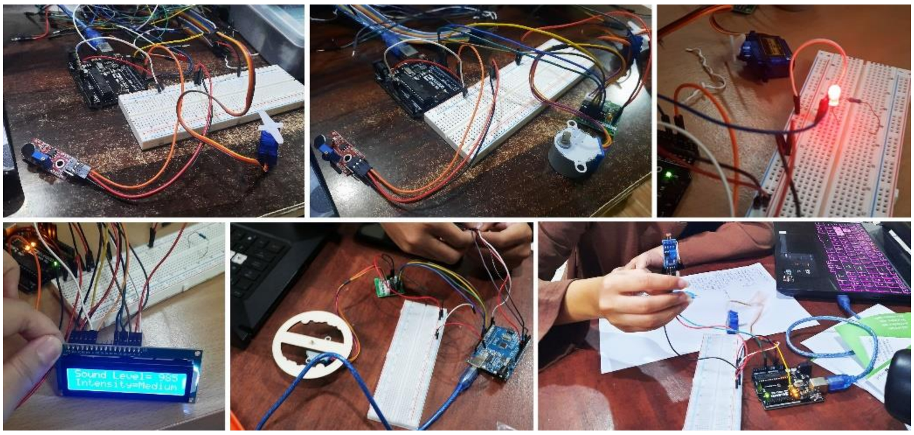

**Fig. 2.** The Arduino experiment documentation

The following data on Table 5 is obtained based on the experimental results and assessment of interactive digital devices using Arduino and its components.

**Table 5.** LDR light sensor test

| Sensor Device | Literature and Experiment Comparison | | |
|---|---|---|---|
| | ***Value*** | ***Condition*** | ***Data Source*** |
| LDR light sensor | 40 - 2800 lux | Light distance: 0.05 - 0.5 m | [36] |
| | 0 - 180 | Light distance: 1 m | Experiment |
| | 180 - 280 | Light distance: 2 m | Experiment |
| KY-038 sound sensor | | 48 - 52 dB | [37] |
| | 980 - 1000 | 30 dB | Experiment |
| | 21 - 23 | Normal rain outside | Experiment |
| | 27 - 31 | Heavy rain outside | Experiment |
| | 20 - 217 | Sensor blown by wind | Experiment |
| KY-028 thermal sensor | Accuracy ± 273.5 K | | [38] |
| | 73 - 74 | Normal | Experiment |
| | 70 - 71 | Sensor covered by hand | Experiment |
| DHT-11 humidity and temperature sensor | 233 - 323 K | | [39] |
| | 273 - 278 K | | [40] |
| | 200000 and 900000 g/m3 | | [40] |
| | Invalid | Invalid circuit data | Experiment |

Based on the literature reviews, LDR can be used to measure light intensity [41], and the LDR light sensor can detect lighting in the 40-2800 lux range with a light source distance of between 0.05 - 0.5 m [36]. LDR can control the light intensity in a room and can be converted to lux meter values. [42]. Based on the experimental results, the LDR sensor produces a value of 0 - 180 when the sensor distance to the light source is 2 m and detects a lighting intensity of 180 - 280 when the distance to the light source is 1 m. The experiment proved that the sensor is sensitive to changes in light intensity. The following method can be applied to achieve the ideal lighting in the workspace. Fig. 3 is methods for implementing ideal artificial lighting in workspaces.

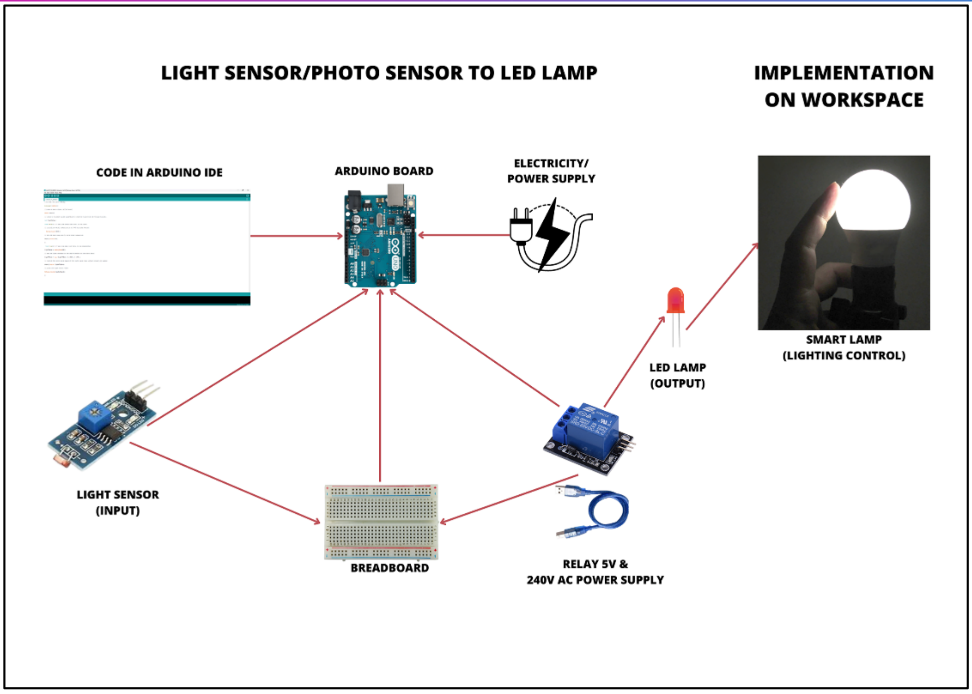


**Fig. 3.** Methods for implementing ideal artificial lighting in workspaces.

Based on a literature review, the KY-038 sound sensor can detect noise levels of 48 - 52 dB and functions to detect the presence or absence of sound in a room [37]. Based on the experimental results, the KY-038 sensor detects 980 - 1000 at a noise level of 30 dB. The sensor detects a value of 21 - 23 when it rains outdoors, then 27 - 31 when the rain gets heavier, and 20 - 217 when the wind blows the sensor. The experiment proved that the sensor is sensitive to changes in sound intensity but cannot reach the ideal comfort range (up to 85 dB). The other type of sound sensor is suggested to be tested to be implemented in workspaces as a smart wall and thermal system. The following method can be applied to achieve the ideal noise level in the workspace. Fig. 4 is methods for implementing ideal natural lighting and thermal levels in workspaces. Fig. 5 is methods for implementing ideal noise and thermal levels in workspaces.

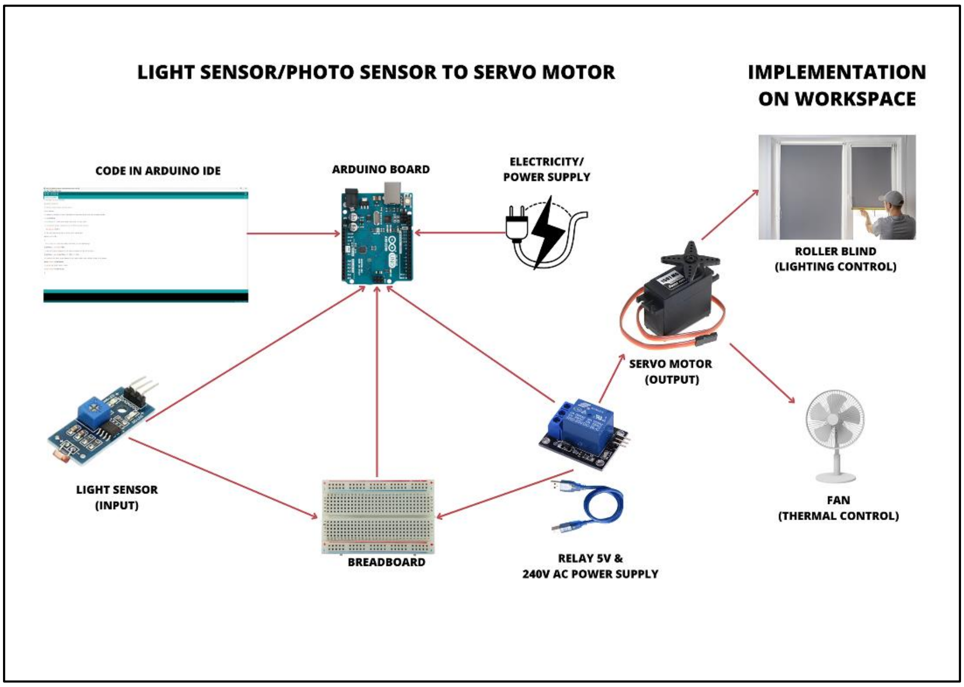


**Fig. 4.** Methods for implementing ideal natural lighting and thermal levels in workspaces.

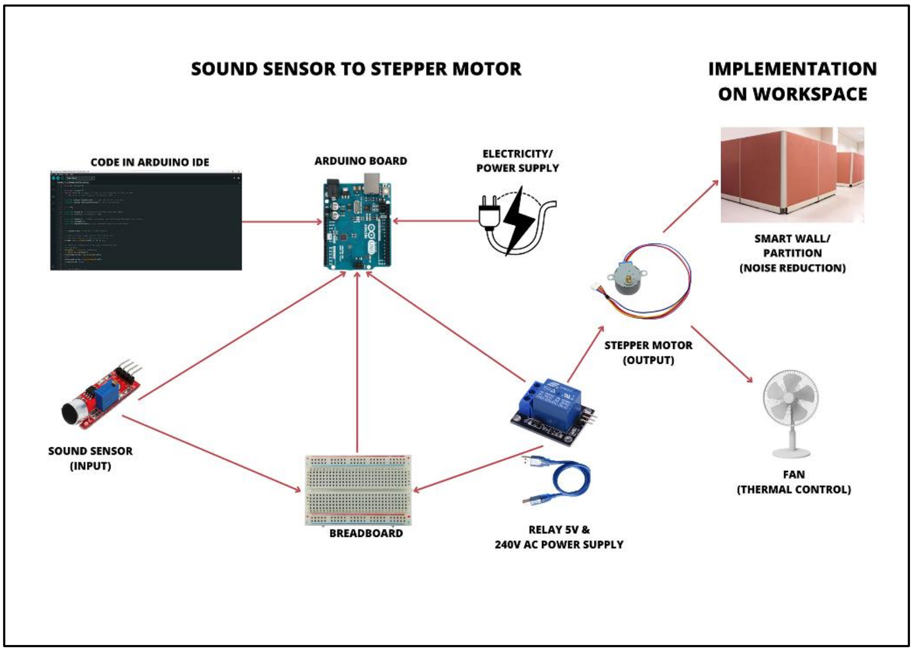


**Fig. 5.** Methods for implementing ideal noise and thermal levels in workspaces

Based on the literature reviews, the KY-028 thermal sensor requires a voltage of 3.3 to 5.5 Volts with an accuracy of ± 273.5 K from the thermometer temperature [38], while based on experimental results, the KY-028 sensor can detect a value of 73 - 74 and drops to 70 - 71 when covered by hand. KY-028 sensor makes it possible to detect temperature changes after several efforts contributed to the environment [43]. The experiment proved that the sensor is sensitive to changes in temperature intensity. The following method can be applied to achieve the ideal temperature level in the workspace. Fig. 6 is methods for implementing ideal thermal levels in workspaces.

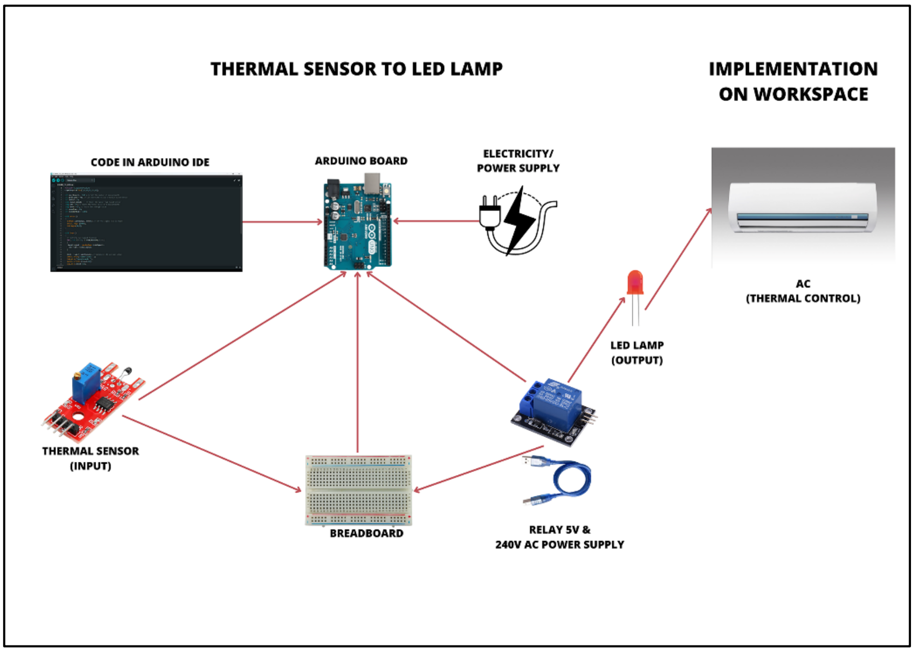


**Fig. 6.** Methods for implementing ideal thermal levels in workspaces

Based on the literature reviews, the DHT-11 sensor can detect temperature and humidity in 233 to 323 K [39]. The DHT-11 sensor can also detect humidity between 200000 and 900000 g/m3 within the operating temperature range of 273 to 278 K range [40]. This sensor is small and has a signal transmission of up to 20 m [44]. The DHT-11 sensor is sensitive to humidity and object temperature [45]. An example of an implementation that can be applied to workspaces is the automation of fans at certain temperatures and humidity. The sensor cannot be proven directly sensitive to temperature and humidity because the experiment cannot be carried out due to technical constraints on the circuit coding. Schematics of ideal temperature and humidity levels in the workspace that are possible to apply based on the study of secondary data through the literature are as follows. Fig. 7 is methods for implementing ideal artificial humidity level in workspaces. Fig. 8 is methods for implementing ideal natural humidity level in workspaces.

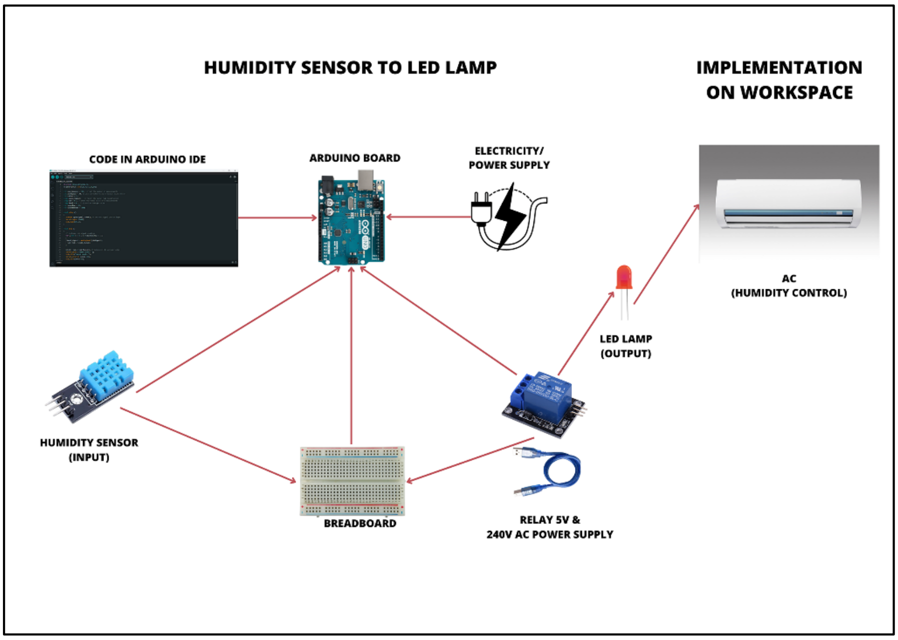


**Fig. 7.** Methods for implementing ideal artificial humidity level in workspaces

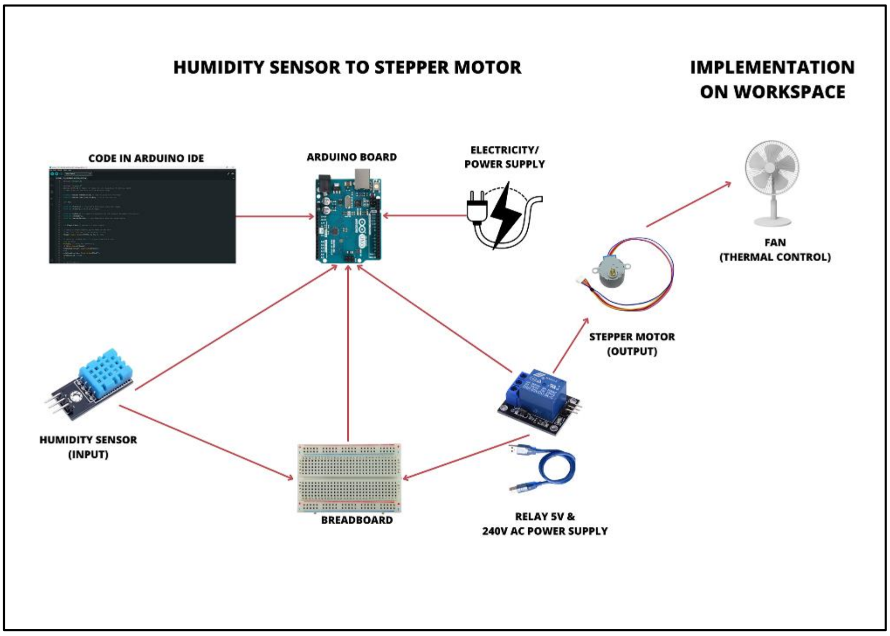


**Fig. 8.** Methods for implementing ideal natural humidity level in workspaces

## 4. Conclusion

Based on the results of literature reviews, ideal comfort workspace based on lighting and noise are varied and relative to the type of work activity, duration of work, and the existing conditions of the geographical environment. The ideal lighting level in the standard workspace is 100 - 500 lux, and the ideal noise level in the workspace for standard work activities is 10 - 85 dB. The ideal comfort workspace based on thermal tends to be similar. The results show that the ideal thermal level in a standard workspace is 293 - 301.5 K or about 20 – 27 ℃, but the ideal temperature to increase work productivity is 293 - 295.5 K or about 20 – 24 ℃ [26]. The ideal humidity level in the workspace is 300000 - 700000 g/m3 for subtropical countries and the ideal humidity for a two-season (tropical) country like Indonesia is 400000 - 500000 g/m3. Based on the results of literature reviews, experiments and studies of interactive digital devices using Arduino and its components, the following conclusions were obtained; (1) The LDR light sensor is sensitive to changes in light intensity and can reach the ideal lighting comfort range. The LDR light sensor can be implemented as a smart lighting and thermal system in workspaces; (2) The KY-038 sound sensor is sensitive to sound intensity but cannot reach the ideal comfort range (up to 85 dB). So, the other type of sound sensor is suggested to be tested to be implemented in workspaces as a smart wall and thermal system; (3) The KY-028 temperature sensor is sensitive to temperature intensity changes and can reach the ideal temperature comfort range. The KY-028 temperature sensor can be implemented in workspaces as a smart thermal system; (4) The DHT-11 sensor is sensitive to humidity and object temperature and can reach the ideal lighting comfort range. The DHT-11 sensor can be implemented as a smart humidity and thermal system in workspaces. The result shows that as an interactive digital device, Arduino can be implemented in a workspace to detect and produce ideal workspace comfort regarding lighting, noise, temperature, and humidity. Arduino also supports flexibility and varied demand in a workspace because of its adjustable artificial intelligence feature. This research suggests using another type of sound sensor that can reach more than 85 dB (according to the ideal standard for workspace noise). This research also enriches the suggestion of implementation in workspace interiors where methods to detect and evaluate them have been designed by several previous studies [8]–[11]. The ideal standard of workspace differs based on the activities and geographical conditions of the country. The ideal standard of workspace is also closely related to differences in user preferences. Based on the complexity, for further research to be carried out, it is recommended to choose the most important aspects to be implemented in a focused and detailed workspace simulation and to conduct a case study to generate more accurate data and suitable workspace design.

## Acknowledgment

Telkom University funded the research under SK: 010/PNLT1/PPM/2023, and Alieja Muhammad Iqbal, an IoT and microcontroller expert, supported the experiment.

## Declarations

| | | |
|---|---|---|
| **Author contribution** | : | All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper |
| **Funding statement** | : | None of the authors have received any funding or grants from any institution or funding body for the research |
| **Conflict of interest** | : | The authors declare no conflict of interest |
| **Additional information** | : | No additional information is available for this paper |

## References

[1] M. W. Memud and B. Tabibi, “Effective Design of Coworking Spaces to Improve Users’ Experience in Lagos State, Nigeria,” *Art Des. Rev.*, vol. 11, no. 02, pp. 80–103, 2023, doi: 10.4236/adr.2023.112007.

[2] M. Kwon, H. Remøy, and M. Van Den Bogaard, “Influential design factors on occupant satisfaction with indoor environment in workplaces,” *Build. Environ.*, vol. 157, pp. 356–365, Jun. 2019, doi: 10.1016/j.buildenv.2019.05.002.

[3] A. Shukur, N. I. . Hussein, S. R. Kamat, and D. Yuniawan, “A Regression Analysis: Ergonomic Comfort vs. Air Quality, Noise, Lighting and Temperature in the Composite Trimming Process Working Room,” *J. Mech. Eng.*, vol. 18, no. 1, pp. 109–121, Jan. 2021, doi: 10.24191/jmeche.v18i1.15168.

[4] S. Ceylan, “Healthy Workspaces: Strategies for Increasing the Indoor Environmental Quality at Call Centre Interiors for Employee Wellbeing and Productivity,” *BUILDER*, vol. 284, no. 3, pp. 60–63, Feb. 2021, doi: 10.5604/01.3001.0014.7430.

[5] G. Gomes Zumba, J. Gomes Zumba, and H. Gomes Zumba, “The contribution of the physical space in medical space,” 2023, doi: 10.54941/ahfe1003689.

[6] L. Bergefurt, R. Appel-Meulenbroek, C. Maris, T. Arentze, M. Weijs-Perrée, and Y. De Kort, "The influence of distractions of the home-work environment on mental health during the COVID-19 pandemic," *Ergonomics*, vol. 66, no. 1, pp. 16–33, Jan. 2023, doi: 10.1080/00140139.2022.2053590.

[7] J. Shin, "Toward a theory of environmental satisfaction and human comfort: A process-oriented and contextually sensitive theoretical framework," *J. Environ. Psychol.*, vol. 45, pp. 11–21, Mar. 2016, doi: 10.1016/j.jenvp.2015.11.004.

[8] W.-T. Sung and J.-A. Shih, "Indoor Thermal Comfort Environment Monitoring System Based on Architecture of IoT," in *2018 International Symposium on Computer, Consumer and Control (IS3C)*, 2018, pp. 165–168, doi: 10.1109/IS3C.2018.00049.

[9] B. Quintana, K. Vikhorev, and A. Adán, "Workplace occupant comfort monitoring with a multi-sensory and portable autonomous robot," *Build. Environ.*, vol. 205, p. 108194, Nov. 2021, doi: 10.1016/j.buildenv.2021.108194.

[10] L. M. Gladence, H. H. Sivakumar, G. Venkatesan, and S. S. Priya, "Home and office automation system using human activity recognition," in *2017 International Conference on Communication and Signal Processing (ICCSP)*, 2017, pp. 0758–0762, doi: 10.1109/ICCSP.2017.8286463.

[11] Z. Li, J. Li, X. Li, Y. Yang, J. Xiao, and B. Xu, "Design of Office Intelligent Lighting System Based on Arduino," *Procedia Comput. Sci.*, vol. 166, pp. 134–138, 2020, doi: 10.1016/j.procs.2020.02.035.

[12] O. E. Amestica, P. E. Melin, C. R. Duran-Faundez, and G. R. Lagos, "An Experimental Comparison of Arduino IDE Compatible Platforms for Digital Control and Data Acquisition Applications," in *2019 IEEE CHILEAN Conference on Electrical, Electronics Engineering, Information and Communication Technologies (CHILECON)*, 2019, pp. 1–6, doi: 10.1109/CHILECON47746.2019.8986865.

[13] Herzberg, Frederick, *Motivation to work*. Routledge, 2017. doi: 10.4324/9781315124827

[14] R. Dale, R. Fusaroli, N. D. Duran, and D. C. Richardson, "The Self-Organization of Human Interaction," in *Psychology of Learning and Motivation*, vol. 59, Elsevier, 2013, pp. 43–95. doi: 10.1016/B978-0-12-407187-2.00002-2

[15] A. Kitson, M. Prpa, and B. E. Riecke, "Immersive Interactive Technologies for Positive Change: A Scoping Review and Design Considerations," *Front. Psychol.*, vol. 9, p. 1354, Aug. 2018, doi: 10.3389/fpsyg.2018.01354.

[16] S. Bakker and K. Niemantsverdriet, "The Interaction-Attention Continuum: Considering Various Levels of Human Attention in Interaction Design," vol. 10, no. 2, pp. 1–14, 2016.

[17] A. A. Masruri and R. Patradhiani, "Faktor Ergonomi Terkait Kenyamanan Ruang Kelas Fakultas Teknik Universitas Muhammadiyah Palembang," *Integr. J. Ilm. Tek. Ind.*, vol. 4, no. 1, p. 40, Dec. 2019, doi: 10.32502/js.v4i1.2097.

[18] K. Indriyani, I. H. Susilowati, A. Dinar, A. Azwar, and M. Wirawan, "Analysis of Ergonomic Factors Related to the Indoor Health Comfort and Musculoskeletal Symptoms of Office Workers," *KnE Life Sci.*, vol. 4, no. 5, p. 200, Jun. 2018, doi: 10.18502/kls.v4i5.2553.

[19] D. Cahyadi and A. Kurniawan, "Pengukuran Lingkungan Fisik Kerja dan Workstation di Kantor Pos Pusat Samarinda," *EKSIS Ris.*, vol. 7, no. 2, pp. 1931–1938, Aug. 2011.

[20] S. Preto and C. C. Gomes, "Lighting in the Workplace: Recommended Illuminance (lux) at Workplace Environs," in *Advances in Design for Inclusion*, vol. 776, G. Di Bucchianico, Ed. Cham: Springer International Publishing, 2019, pp. 180–191. doi: 10.1007/978-3-319-94622-1_18

[21] R. S. Saraswati, B. A. Wibawa, and B. E. Saputra, "Optimization of Natural and Artificial Lighting System in UPGRIS Lecturer's Workspace using Dialux Evo," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 738, no. 1, p. 012033, Apr. 2021, doi: 10.1088/1755-1315/738/1/012033.

[22] P. E. Dora, "Hubungan arah pencahayaan buatan terhadap kenyamanan dan efisiensi kerja," *Semin. Nas. Dies Jur. Arsit. Univ. Kristen Petra*, pp. 1–8, 2012.

[23] N. S. Abdelaziz Mahmoud, G. El Samanoudy, and C. Jung, "Simulating the natural lighting for a physical and mental Well-being in residential building in Dubai, UAE," *Ain Shams Eng. J.*, vol. 14, no. 1, p. 101810, Feb. 2023, doi: 10.1016/j.asej.2022.101810.

[24] J. M. Katabaro and Y. Yan, “Effects of Lighting Quality on Working Efficiency of Workers in Office Building in Tanzania,” *J. Environ. Public Health*, vol. 2019, pp. 1–12, Nov. 2019, doi: 10.1155/2019/3476490.

[25] R. Golmohammadi, M. Aliabadi, and T. Nezami, “An Experimental Study of Acoustic Comfort in Open Space Banks Based on Speech Intelligibility and Noise Annoyance Measures,” *Arch. Acoust.*, vol. 42, no. 2, pp. 333–345, Jun. 2017, doi: 10.1515/aoa-2017-0035.

[26] D. Gavhed and A. Toomingas, “Observed physical working conditions in a sample of call centres in Sweden and their relations to directives, recommendations and operators’ comfort and symptoms,” *Int. J. Ind. Ergon.*, vol. 37, no. 9–10, pp. 790–800, Sep. 2007, doi: 10.1016/j.ergon.2007.06.006.

[27] I. V. Owolawi, “Noise Exposure and Its Auditory Effect on Industrial Workers,” *Int. J. Otolaryngol. Head & Neck Surg.*, vol. 10, no. 05, pp. 365–375, 2021, doi: 10.4236/ijohns.2021.105033.

[28] N. Vujica Herzog, B. Buchmeister, and L. Spindler, “Assessment of School and Industrial Noise: Measurements vs Personal Perceptions,” in *DAAAM International Scientific Book*, 1st ed., vol. 19, B. Katalinic, Ed. DAAAM International Vienna, 2020, pp. 033–048. doi: 10.2507/daaam.scibook.2020.03

[29] D. Gavhed and A. Toomingas, “Observed physical working conditions in a sample of call centres in Sweden and their relations to directives, recommendations and operators’ comfort and symptoms,” *Int. J. Ind. Ergon.*, vol. 37, no. 9–10, pp. 790–800, Sep. 2007, doi: 10.1016/j.ergon.2007.06.006.

[30] A. Chen and V. W.-C. Chang, “Human health and thermal comfort of office workers in Singapore,” *Build. Environ.*, vol. 58, pp. 172–178, Dec. 2012, doi: 10.1016/j.buildenv.2012.07.004.

[31] H. B. Rijal, M. A. Humphreys, and J. F. Nicol, “Behavioural Adaptation for the Thermal Comfort and Energy Saving in Japanese Offices,” *J. Inst. Eng.*, vol. 15, no. 2, pp. 14–25, Jul. 2019, doi: 10.3126/jie.v15i2.27637.

[32] J. Soto Muñoz, M. Trebilcock Kelly, V. Flores-Alés, and R. Ramírez-Vielma, “Understanding the perceived productivity of office occupants in relation to workspace thermal environment,” *Build. Res. Inf.*, vol. 50, no. 1–2, pp. 152–170, Feb. 2022, doi: 10.1080/09613218.2021.1897501.

[33] J. Liu, X. Yang, X. Meng, and Y. Liu, “Effects of Indoor Temperature and Air Movement on Perceived Air Quality in the Natural Ventilated Classrooms,” 2018, p. 275.

[34] C. B. Ramspeck *et al.*, *Thermal environmental conditions for human occupancy*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2004.

[35] J. Razjouyan *et al.*, “Wellbuilt for wellbeing: Controlling relative humidity in the workplace matters for our health,” *Indoor Air*, vol. 30, no. 1, pp. 167–179, Oct. 2019, doi: 10.1111/ina.12618.

[36] D. A. Wulandari and H. S. Pramono, “Pengembangan robot multinavigasi untuk media pembelajaran pada mata pelajaran robotika program keahlian mekatronika di SMK Negeri 3 Wonosari,” *J. Pendidik. Tek. Mekatronika*, vol. 8, no. 7, pp. 622–632, Nov. 2018.

[37] M. P. Lukman, . J., and Y. F. Y. Rieuwpassa, “Sistem lampu otomatis dengan sensor gerak, sensor suhu dan sensor suara berbasis mikrokontroler,” *J. Resist. (Rekayasa Sist. Komputer)*, vol. 1, no. 2, pp. 100–108, Oct. 2018, doi: 10.31598/jurnalresistor.v1i2.305.

[38] H. Kuswoyo, E. Susana, and H. Tjahjadi, “Design of Personal Health Monitoring Devices for Early Detection of Silent Hypoxia,” *Teknik*, vol. 43, no. 1, pp. 8–16, May 2022, doi: 10.14710/teknik.v43i1.42752.

[39] D. R. Arivalahan, “Development of Arduino based microcontroller through Internet of Things (IoT) for the measurement and monitoring of process environmental parameters,” *Iaeme*, vol. 12, no. 2, pp. 50–61, Feb. 2021, doi: 10.34218/IJEET.12.2.2021.006.

[40] W. Gay, “DHT11 Sensor,” in *Advanced Raspberry Pi*, Berkeley, CA: Apress, 2018, pp. 399–418. doi: 10.1007/978-1-4842-3948-3_22

[41] W. Setya *et al.*, “Design and development of measurement of measuring light resistance using Light Dependent Resistance (LDR) sensors,” *J. Phys. Conf. Ser.*, vol. 1402, no. 4, p. 044102, Dec. 2019, doi: 10.1088/1742-6596/1402/4/044102.

[42] G. Kilari, R. Mohammed, and R. Jayaraman, “Automatic Light Intensity Control using Arduino UNO and LDR,” in *2020 International Conference on Communication and Signal Processing (ICCSP)*, 2020, pp. 0862–0866, doi: 10.1109/ICCSP48568.2020.9182238.

[43] G. B. Alves, “Umistick: Developing a Blow-Based Joystick Using Arduino Sensors and a Printed Circuit Board,” 2018.

[44] D. Srivastava, A. Kesarwani, and S. Dubey, “Measurement of Temperature and Humidity by using Arduino Tool and DHT1,” vol. 05, no. 12, 2018.

[45] M. O. Sabir, P. Verma, P. K. Maduri, and K. Kushagra, “Electrically controlled artificial system for organic waste management using Black Soldier Flies with IOT monitoring,” in *2020 2nd International Conference on Advances in Computing, Communication Control and Networking (ICACCCN)*, 2020, pp. 871–875, doi: 10.1109/ICACCCN51052.2020.9362816.