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Design and Implementation of an IoT-Based Smart Classroom Incubator

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Abstract: Ambient conditions influence human health, emotions, and mental power. Therefore, numerous studies have been conducted in different disciplines on the measurement and control of ambient conditions in classrooms. Moreover, a number of studies identify some physical and mental performances of students simultaneously or for informative purposes by utilizing various hardware and software. However, these studies did not consider automatic control processes and individuality in fulfilling classroom ambient conditions, which influence students' behavior. This study aims to reduce the adverse impacts of environmental factors on learning and control more necessary physical parameters with higher accuracy using the latest technology and methods. Thus, a new smart classroom incubator (SCI) algorithm, including hardware, software, and experimental studies, in which individual differences could be considered even in the same classroom environment, and its implementation were presented. The system enables access and monitoring of data wherever there is Internet connection. Moreover, it was designed based on IoT because it allows for data transfer over web services or data-dependent operations. All the necessary equipment was placed in the classroom without affecting the learning environment and distracting the class. Cronbach's α coefficient, which indicates the reliability of the implemented model, was 0.891.

Keywords: smart classroom; smart classroom incubator; classroom automation; control of environmental factors; IoT

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1. Introduction

The effects of the physical parameters of ambient conditions on people may vary according to age, health status, work, etc. This is similar to Hippocrates's statement, "There is no disease, but the patient," which is considered the main principle of the right medical practice. Particularly in educational institutions, the ambient conditions in classrooms affect the learning efficiency. However, the degree of this effect cannot be assessed accurately and adequately due to variations and fluctuations in ambient conditions and the inability to keep all the variables under control. Previous studies did not approach these factors holistically. Studies were conducted on only the control or effects of some variables or conditions.

Furthermore, hardware or methods, which either disrupt the natural conditions of the measurement environment or are expensive, are used in practice. Therefore, these are not sustainable and useful. Smart teaching aids should also have a healthy physical environment [1]. Moreover, it is difficult to create a system that can meet the needs of all students without considering the individual differences [1]. However, in many studies on students' affective state levels, physical conditions were not controlled. Saini and Goel reported that a complete smart class would be costly due to its infrastructure requirements [1]. Therefore, a cost-effective solution will increase sustainability and applicability.

At the same time, it is essential that the elements controlling these variables in the environment do not affect the general physical environment negatively and do not distract attention. Ricciardi and Buratti defined comfort conditions in their measurement and survey studies based

on thermal and acoustic properties and lighting in an environment [2]. Zuhaib et al. stated that the problem of heating could be decreased with improvements such as the arrangement of heating programs and adequate mechanical ventilation [3]. Likewise, Bajc et al. conducted an experimental study on the effect of thermal comfort and revealed the adverse effects of high temperature and carbon dioxide [4]. Haverinen-Shaughnessy and Shaughnessy observed the effect of ventilation and air conditioning on grades [5]. In their experimental study, Almaqra et al. thought that air temperature might affect students' cognitive performance [6]. Tagliabue et al. concluded that indoor air quality and thermal conditions could improve the learning performance of users and energy savings [7]. Zaki et al. reached a conclusion that thermal comfort conditions varied between individuals [8]. Ceranic et al. stressed the importance of smartly managing thermal, ventilation, and humidity control strategies adapting to climate, season, and weather [9]. Song et al. used skin temperature for air conditioning control [10].

Cheryan et al. expressed that the learning environment deeply affected learning and success level [11]. Najafi et al. concluded that the sound level should be between 35 and 45 dB in a classroom, and a combination of artificial and natural light could be beneficial for classroom lighting [12]. Sahin et al. demonstrated that the light wavelength influenced a person's wakefulness and performance [13,14]. Smolders and de Kort also observed the effects of bright light [15]. Yang and Jeon observed the effects of led light on cognitive performance [16]. de Rubeis et al. conducted a study on lighting control, cost, and energy savings [17]. Keis et al. reported that the cognitive processing speed and concentration of students increased under the lighting conditions they recommended, compared to standard lighting conditions [18]. Sun et al. presented an effective lighting control model [19].

Some studies investigate the effects of particulate matter on health and measure its amount [20–23]. Yang and Moon tested the ambient air quality conditions [24]. Twardella et al. revealed that classroom air quality influenced student performance [25]. Stazi et al. implemented and observed an automatic window opening system to improve air quality [26]. Dutta et al. enabled ventilation in the environment with IoT-based fan control [27].

Klatte and Sutjarittham et al. equipped classrooms with IoT sensors to measure real-time utilization and used artificial intelligence techniques to predict attendance [28,29]. In their experimental study, Ahmawati et al. proved that the physical environment of the classroom affected the learning motivation of students considerably [30].

Examination and model proposition studies measure, observe, or locally control physical conditions using different methods [1,31–33]. Furthermore, experimental studies conducted in classroom environments ignored the effect of physical classroom conditions [34–48]. In learning environments, the main purpose is learning efficiency. However, some studies paid attention only to energy efficiency while controlling the ambient variables [49–51]. Some studies examined the usability and future classroom technologies and presented architectural, smart model, and data management proposals regarding the arrangement of the inside and outside of the classroom in these respects [52–59]. In some other studies, Multimedia Learning Technologies based on loT, physiological measuring instruments, cost effective digital systems' hardware were used to increase the quality and efficiency of education [60–62]. As can be seen, when studies on this subject in the literature are reviewed in a bit more detail, it is realized that these studies were generally conducted in the fields of social sciences or educational sciences, and measurements and observations were made, and findings were obtained in this regard. Therefore, the technical aspect of the subject is missing. Moreover, there are no studies in which all the relevant variables were controlled according to general or individual requirements using an engineering approach toward learning environment and efficiency. Consequently, it is clear that the effects of ambient conditions on learning are important. Nevertheless, it would be more useful to approach variables as a whole and include individuality as much as possible.

Accordingly, some of the most important factors influencing the learning environment are sound intensity and distribution, temperature, relative humidity rate, light intensity, air quality, and ambient pollution. Therefore, this study measured the above-mentioned parameters. On the other hand, the most important control parameters are individualized

temperature control, automatically controlled position-based lighting, improved air quality, and ambient cleanliness. The sound distribution in the classroom was also measured, mapped, and made more homogeneous.

This study used engineering approach and engineering methods, and the above-mentioned parameters were monitored simultaneously and controlled by automation. Unlike previous studies, a higher number of necessary parameters could be monitored and controlled individually. An adaptive software algorithm that used dynamic values instead of fixed values, which are considered standard, was used to control the parameters. In this SCI, the focus was set on maintaining the learning efficiency and health of students, and student readiness in education could be monitored instantly with IoT. The study's validity was confirmed by analyzing the data collected from SCI and ordinary learning environments, survey studies, and experimental study results. Hence, the benefits of this study in real learning environments were presented.

2. Materials and Methods

In this study, the most significant variables that influenced smart classroom management were considered as light intensity, temperature, relative humidity rate, air cleanliness, sound intensity and distribution, the amount of dust and particulate matter. The analog and digital data regarding these parameters are monitored as mobile using software. Moreover, the control of parameters was individualized. For example, students can enter the desired temperature value simultaneously and instantly with a button on their desks. In the system, the temperature is not kept constant at ideal or standard values. Instead, the average values of individual differences are calculated and updated dynamically and continuously. Ambient variables and these calculated values are evaluated and controlled by an adaptive algorithm. For example, in addition to sensors, individual heating and cooling units were installed on the desk and table of each student.

Because relative humidity rate and temperature are directly correlated with each other, they are controlled together using an additional fan. The level of light intensity needed can also change individually. Therefore, light intensity was kept at a certain value and controlled by taking into account its reflection in the classroom. Air quality is important in terms of the momentary mental efficiency and health of a person. Especially during the pandemic, the cleanliness and sterilization of the environment have gained more importance. These parameters, which affect the learning environment, were controlled. The sound intensity and distribution of the teacher in the classroom were measured, and a sound distribution map was obtained. Sound distribution was made more homogeneous by providing the necessary feedback.

This study was conducted in Private Ankara Chamber of Industry Vocational and Technical Anatolian High School classrooms. First, the existing physical conditions of the classrooms in this educational institution were identified: 19 of the 24 classrooms in the school are located on the same facade. The average classroom areas are 51 m^2, and the height of the ceilings is 3.5 m. Class sizes are limited to 24 people. All classrooms have a blowing-type heating and cooling system, roller blinds, and smartboards.

Before and after installing the automation system, the data on these variables in the environment were collected with the sensor systems, and their time-dependent web-based records were kept. To determine the increase in efficiency, the experimental group in the classroom with system installation and the control group in the classroom without system installation were lectured. For identical education, both groups were lectured by the same teachers from five different branches. Then, a test covering five different courses was applied to the subjects simultaneously. Afterward, the success of both groups was compared. Identical levels of readiness for education were ensured in both groups. To this end, the percentiles of the secondary education transition exam were taken into consideration. Confirmation was ensured by statistical methods by providing different groups with different education and applying the test a few times. Moreover, the students' satisfaction was measured through surveys.

To increase the popularity of this system, hardware with the lowest cost was used. While designing the system, importance was given to ergonomics. Unlike other studies, all the system and measurement instruments were placed in a way that would not affect the learning environment. Thus, the motivation of students and the visual order were not disturbed. The manual control of the ambient conditions such as sound, light, etc., during the lesson can be distracting and affect classroom management. However, this negativity, which is often ignored, was eliminated with the automation in this study. Additionally, this automation system also increases energy efficiency by ensuring more efficient use of the school's heating and lighting resources. On the other hand, the digital transformation targeted in Industry 4.0 was partially achieved in the field of education with this system.

2.1. SCI Physical Conditions and Hardware

The IoT-based SCI shown in Figure 1 can be used to measure and control all the parameters of the physical conditions in the environment. It is also possible to use any parameter, whose effect is desired to be observed, as a controlled variable. For this purpose, data of eight different variables were received with 76 sensors from 13 different positions using 18 processors seen in Figure 1, and seven types of actuators were controlled in 24 different positions. At the same time, these data were transferred to the cloud system via IoT so that the data could be monitored when required and converted into a database to be used in analyses. For sustainability and applicability, in addition to the previously mentioned ergonomics, processors, sensors, and hardware with sufficient capacity and the lowest cost were used to collect data.

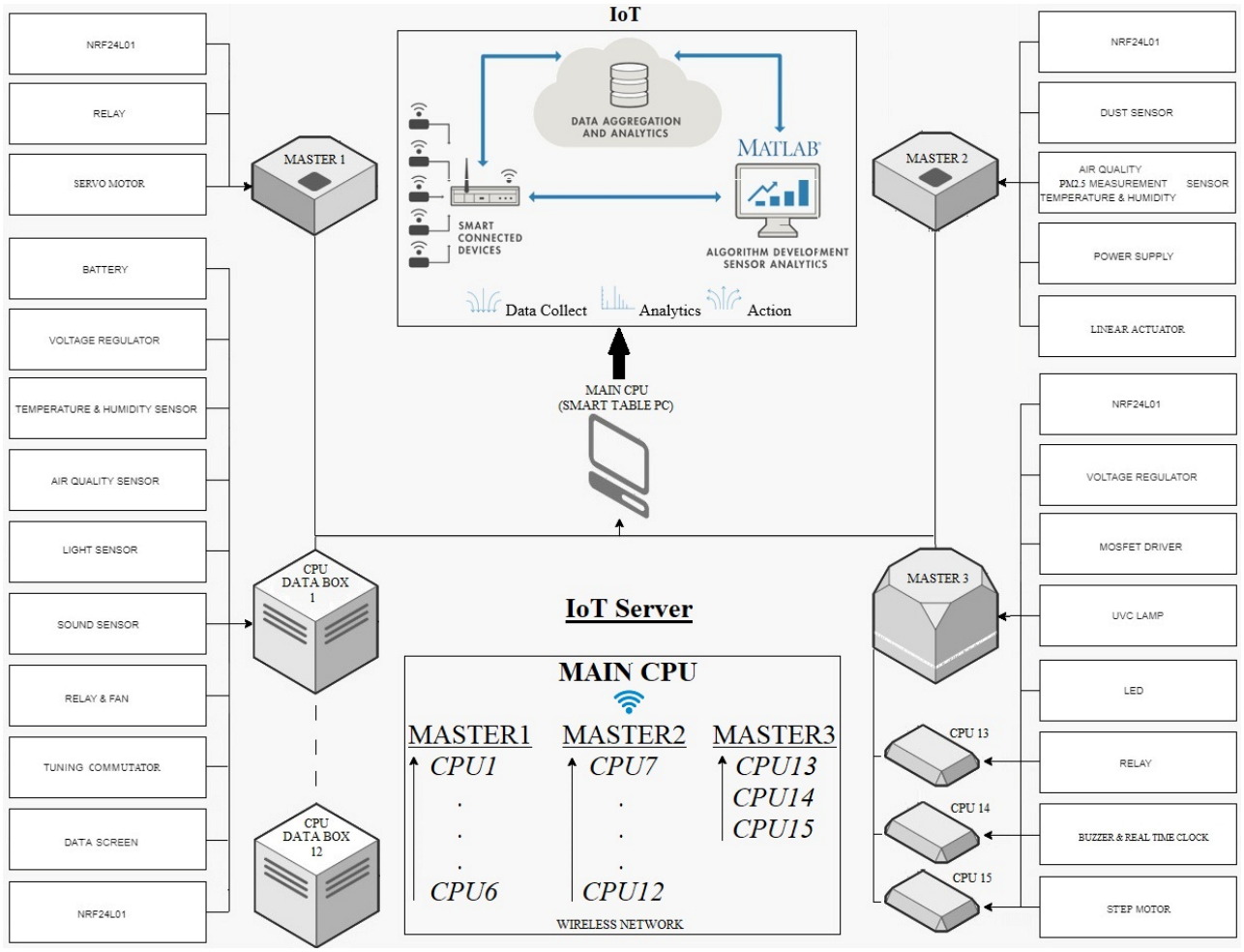


Figure 1. System structure of the SCI.

Figure 2 shows the seating plan of students with numbers 1–12. From these 12 different positions, six types of data are obtained: temperature, humidity, light, sound intensity, air quality, and individual temperature preference. Five types of data, namely outdoor air quality, PM2.5 value, dust amount, temperature, and humidity, are received from the section where natural ventilation is controlled, which is expressed with number 13 and letter A in Figure 2. Each of these data is processed with different processors, and the natural ventilation system, dynamic air conditioning system, dynamic lighting system, personal air conditioning system, UVC sterilization system, and roller blind positioning system are controlled automatically.

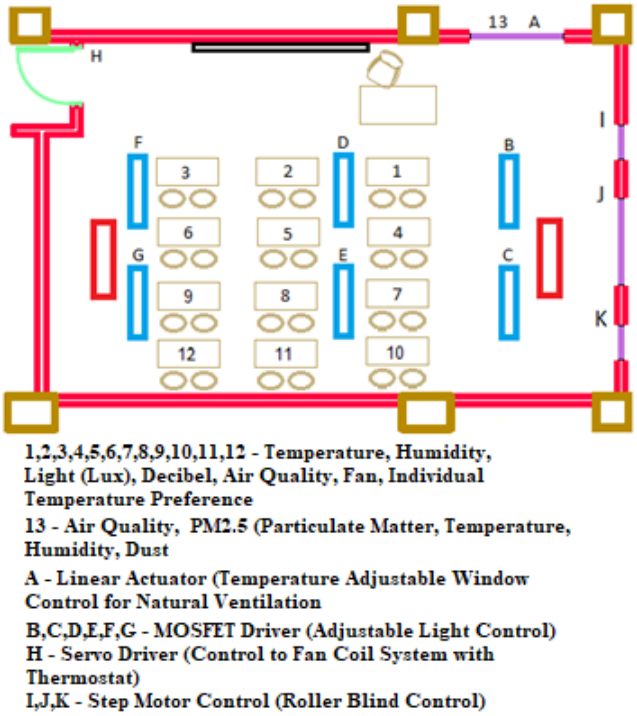


Figure 2. The layout of the SCI's measurement and control points.

Moreover, the data transferred to the cloud via IoT were analyzed, and it was possible to provide feedback to teachers, school administration, or parents over web services. The sound level of the teacher, which reached the students' positions during the lesson, was recorded with sound sensors. A sound distribution map was obtained using these data, and an experimental study in which its effects were observed as uncontrolled variables was conducted. When necessary, these data can be sent through applications such as web services. Thus, the relevant units can be notified or warned on matters such as the cleanliness of the classroom. For such situations, the system is open to development and can be easily fixed. Figure 3 shows the classroom in which the system was applied.

The dimensions of the classroom where the implementation was carried out and the geographical position of the classroom are presented in Figure 4.

2.1.1. Data Box and Personal Air Conditioning System

There is a data box designed to make measurements at all positions numbered from 1 to 12 in Figure 2. On this box, there is a display where students can see the collected data and a tuning commutator to enter the personal temperature value. The collected data are transmitted wirelessly to the processor called MASTER1 (Figure 1). The average classroom temperature is calculated using the values received from a total of 12 positions. However, if a student requests a value different from the average value, the personal air conditioning fan on the student's desk is activated. This hardware has a central processor card. With this card, the data of other sensors can also be used in the classroom automation system and transferred to the IoT system. In each box, there is a sound sensor, light sensor, temperature and humidity sensor, air quality sensor,

wireless communication card, double relay card, battery slot, regulator card, and processor. Figure 5 shows the basic algorithm of this system's software.



Figure 3. The classroom with the installed smart classroom incubator (SCI).

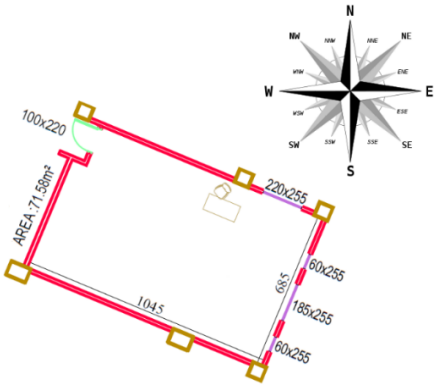


Figure 4. Dimensions (cm) and geographical position of the SCI.

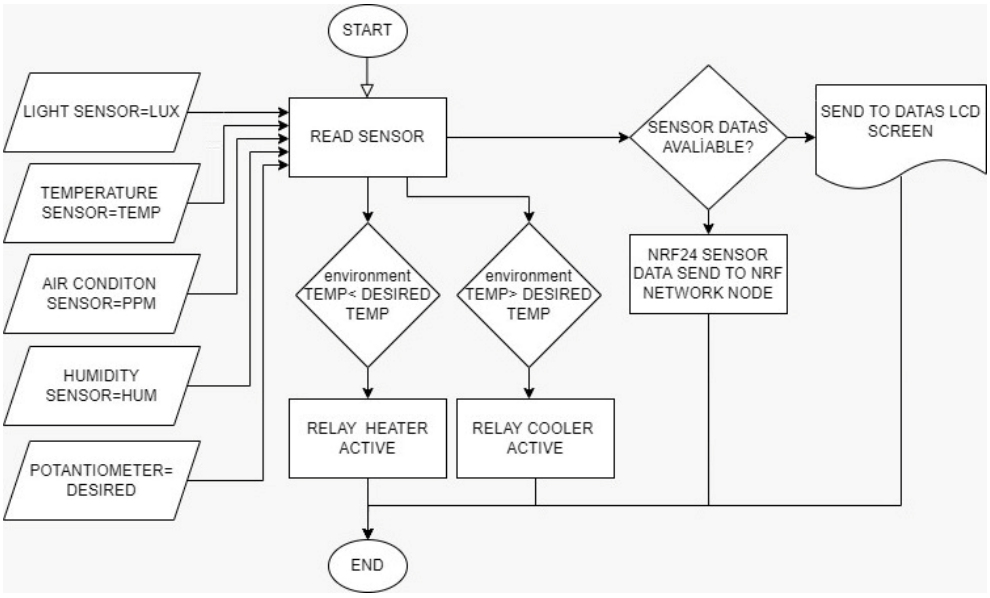


Figure 5. The basic algorithm of the software of the data box.

The structure of the SCI system is very complex since it contains a lot of data and a sensor network. However, it has a simple interface so that students cannot be distracted and prevented from focusing on the lesson and do not waste time with it. Therefore, each student can only see the data on their desk using this interface and enter the temperature demand for personal air conditioning. The images of the interface are presented in Figure 6.

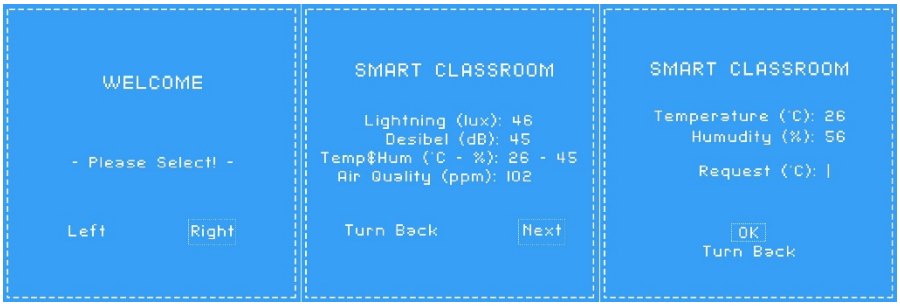


Figure 6. Data box interface.

2.1.2. Outdoor Air Quality Measurement and Natural Ventilation System

The system enables natural ventilation when necessary. For this purpose, there is a temperature, humidity, PM2.5 particulate matter ratio and air quality sensor, dust sensor, wireless communication card, motor driver card, regulator, battery, and processor in position 13 (in Figure 2). There is also a linear actuator to open or close the window in position A. If the air quality is lower than the determined level according to the data received from the data boxes in the classroom, the temperature, humidity, PM2.5 particulate matter ratio in front of the window, and the data received from the sensors that measure the air quality are compared. Thus, the linear actuator is activated, and the window opens. The window is kept open for the required time to enable natural ventilation (Figure 7). If the measured outdoor air temperature differs from the temperature measured indoors, the dynamic air conditioning system in the classroom is activated. Figure 8 shows the basic algorithm of this system's software.



Figure 7. Natural ventilation system.

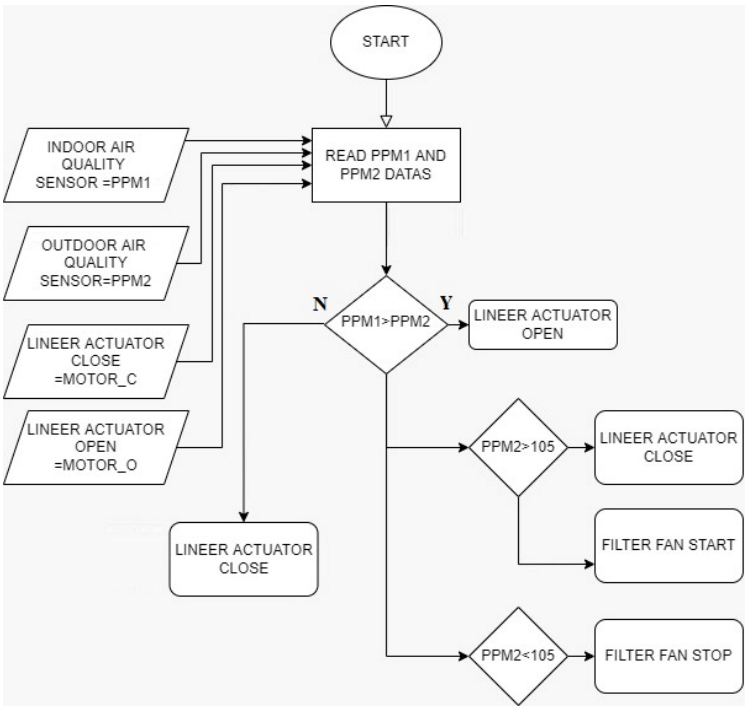


Figure 8. The basic algorithm of the software of the natural ventilation system.

2.1.3. Dynamic Lighting and UVC Sterilization System

Dynamic lighting and UVC sterilization system have been used in the SCI. For lighting, LED lighting panel was placed in each of the B, C, D, E, F, G positions (Figure 2). The panels placed with both sides were driven in parallel. In Figure 2, there are roller blinds in positions I, J, and K. The dynamic lighting system also controls them. Accordingly, it prevents students from exposure to direct sunlight and ensures making use of natural lighting as much as possible. A wireless communication card, buzzer, MOSFET driver, real-time clock module, processor, and UVC lamp were placed between these panels. Three step motors were used to control the roller blinds individually. Light sensor data and a real-time clock module are used to control the roller blinds. In line with the light sensor data received from positions 1, 4, 7, 10, 2, 5, 8, 11 and 3, 6, 9, 12 in Figure 2, LED panels in positions B, C, D, E and F, G are driven. Moreover, the environment is sterilized between 03:00 and 04:00 at night when the school is closed. To this end, a UVC lamp and buzzer system (for warning) are used. The basic algorithm of the system's software is given in Figure 9.

2.1.4. Dynamic Air Conditioning System

Dynamic air conditioning system has been used in the SCI. For this purpose, in Figure 2, there is a fan coil control panel in position H and a fan coil air conditioning system in each of two positions represented by red rectangles. As a standard, the fan coil system has three different fan blowing levels and thermostatic control. The thermostatic part was normally controlled manually by a potentiometer. For the automatic control of this unit, a servo motor was connected to the shaft of the potentiometer. To adjust the fan speed, another servo motor was used. These servo motors were driven using the average values of the temperature data received from positions 1–12 in the classroom. A relay driver was used for on-off operation. A processor and a wireless communication card were used for these operations. The system is shown in Figure 10.

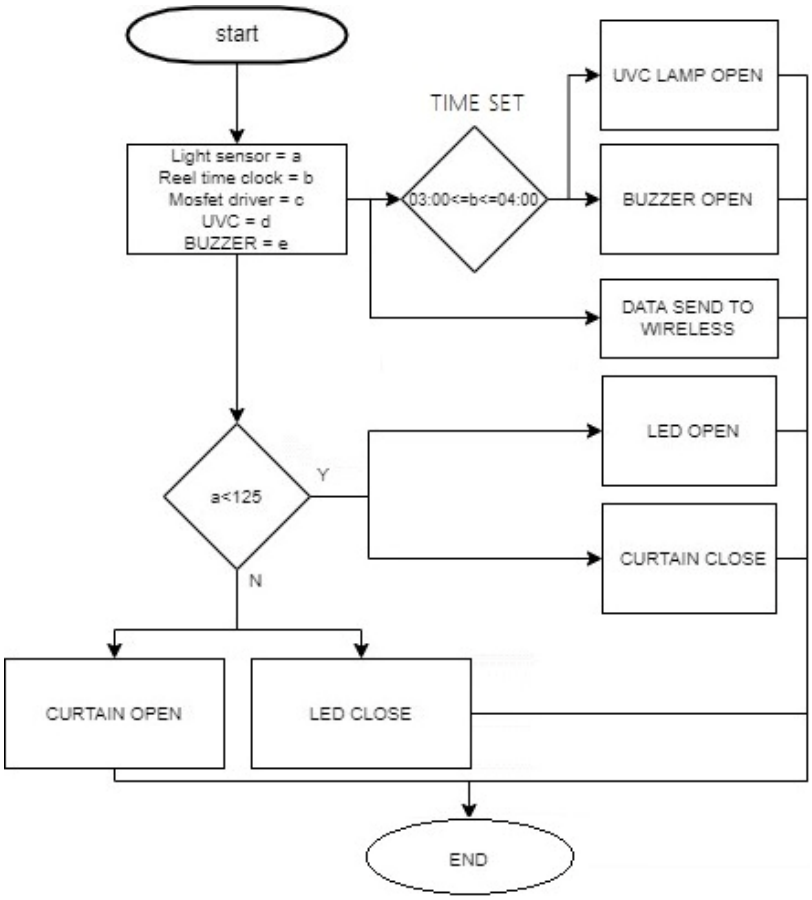


Figure 9. The basic algorithm of the software of the dynamic lighting and UVC sterilization system.

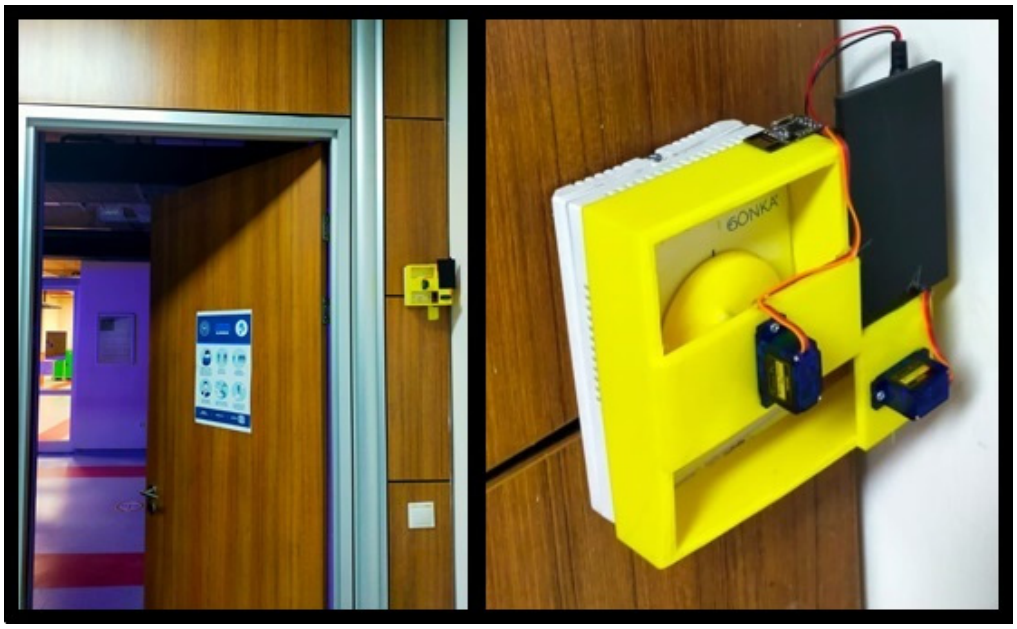


Figure 10. Dynamic air conditioning control system.

2.2. Data and Network Topology

The data collected from sensors are 10 bits. Some arithmetic formulae were used to interpret these data. The range of these values was adapted to the actual values. A smartboard computer is used as the main processor. The processors communicate with the web service in the computer using the wireless communication protocol. Data obtained from the classroom are collected with the Python Service that runs on the smartboard. The Data Collection System has three independent Python web services running on the server computer. The Python Service serially communicates with the main processor and requests instant data of the desired sensor from the processor in a certain order and sends the response to the ThingSpeak Platform with RESTAPI. This process is repeated every 20 s for each sensor. Since the dynamic speeds of the variables are low, an interval of 20 s is appropriate for receiving each data.

Communication with NRF24L01 microcontrollers, which are used for wireless data transfer, is enabled with the SPI communication protocol. The NR24L01 communication chip has the capacity to run 6 transmitters simultaneously in a star topology. Since the number of transmitters was more than 6, a network design was made with tree topology in this study. In a tree topology, each node can have a maximum of 5 sub-nodes, which can go deep at 5 levels. This means that a network of 3125 nodes in total can be created.

Based on the tree topology method in Figure 11, there is a master NRF24L01, three NRF24l01 nodes, and five slave NRF24L01s under each of these nodes in the system. Microcontrollers with each slave transmitter transfer the data they read at 20 s intervals to a higher node to which they are connected. All nodes transfer the data to the controller where the master NRF24l01 is located. All data collected on the master controller are sent to the main processor and transmitted to the IoT system. A structure consisting of variables, as seen in Figure 11, is designed, and the data read from the controllers are sent to the next receiver as a data package. In this structure, the variable named "nodenumber" was used so that the master controller could analyze which transmitter the sent data came from. This variable must be a unique number for all transmitter controllers with NRF24101.

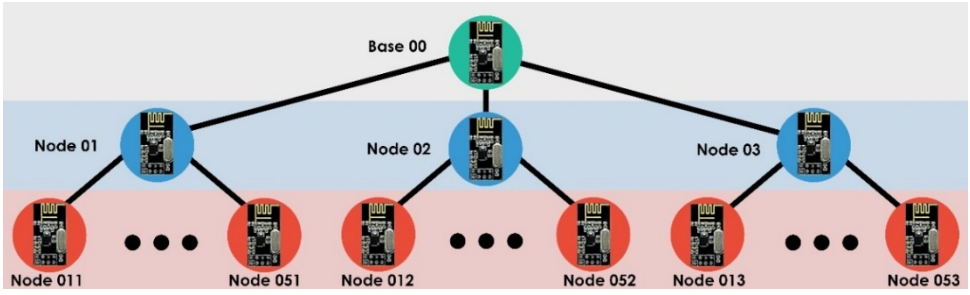


Figure 11. Tree topology diagram.

IoT-Based Data Monitoring

The ThingSpeak web platform was used to monitor data simultaneously and act. As seen in Figure 12, an account is opened through the application. Four channels are created in this account. Eight fields are opened in each channel, and a total of 32 data can be displayed and recorded. The time and date when each data was received can be seen on the chart.

With this application, an IoT analysis platform service, which enabled the collection, visualization, and analysis of live data streams in the cloud, was obtained. The application provides instant visualization of the data sent by devices. With the ability to run the MATLAB code on the website, data can be analyzed and processed online. The application communicates with connected devices and people. It usually provides sensor data to cloud storage and cloud computing resources, where data are processed and analyzed for monitoring. Many high-level IoT systems can be defined using the IoT diagram in Figure 1.



Figure 12. Data visualization.

3. Results

In this study, a case study was carried out using the designed SCI system in a real education environment. Information about the study, the statistical surveys applied, the results obtained, etc., are presented in the following sections.

3.1. Case Study

In this study, first, sensor mechanisms used to measure variables and collect data were set up. Before installing the automation system, one-day monitoring was carried out in 24 classrooms using these sensors, and the data were used for needs analysis. In line with the data received from the sensors, the value range of the parameters varies substantially during the day when there is no automatic control in classrooms. Based on this observation, a 5-point Likert-type questionnaire that consisted of 30 questions (Strongly agree (5), Agree (4), Undecided (3), Disagree (2), and Strongly disagree (1)) and measured the effects of physical conditions was applied to students to determine their needs. After the survey and measurement results were analyzed, the classroom automation was installed.

In Turkey, students are subjected to the secondary education transition exam at the end of the 8-year compulsory primary education system. This exam includes 20 mathematics, 20 science, 20 Turkish, 10 history, 10 religious culture and moral knowledge, and 10 English questions. Students are placed in the schools they have written in the preference list according to the scores they have received in this exam. Students' classes are also determined according to these placements. Thus, identical distribution is ensured. In the study, 24 students were included in the experimental group and 24 students in the control group. First, the experimental and control groups attended 30-h lessons, which were presented by the same teachers in five different branches, namely Mathematics, Physics, Chemistry, Biology, and Turkish, every week for five weeks. They were then subjected to examination. It was observed that the average score of students in the classroom where the automation system defined as SCI was installed was 85, and the average score of students studying in the classical classroom was 74. The coding showing students' positions in the classroom for score comparison is presented in Figure 13.

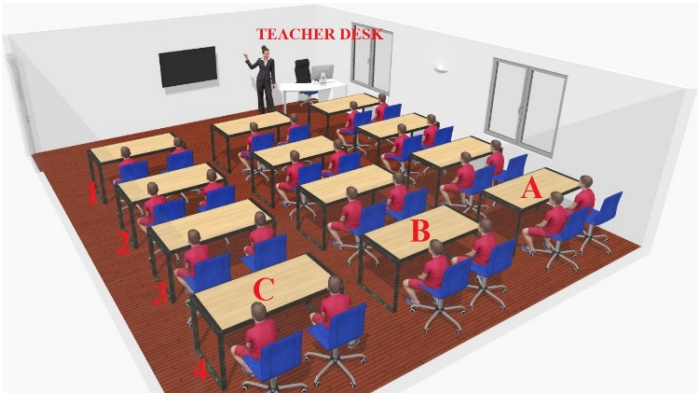


Figure 13. Coding that represents students' positions.

During the lessons, the sound distribution of 10 teachers was measured at 12 points where the students' desks were located. Accordingly, sound distribution maps were obtained. If the sound level was inadequate in any part of the classroom or if there was an indoor or outdoor noise that prevented hearing, the teacher was warned visually with a sound distribution map at the end of the lesson. The data distribution chart of the teachers who were provided with feedback, obtained after 3 weeks, is presented in Figure 14. It was observed that the relevant course success of the teachers who taught in the SCI became similar to each other independently of the positions, and the teachers ensured a more homogeneous sound distribution.

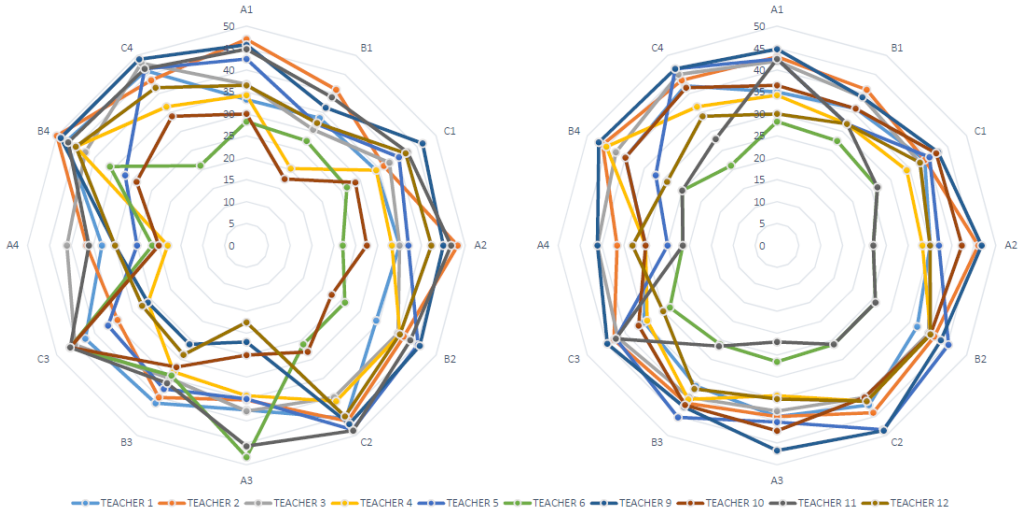


Figure 14. Teachers' sound distribution measurements before (on the **left**) and after (on the **right**) feedback.

3.2. Statical Survey

The model's reliability in the study was tested with Cronbach's α coefficient. A Cronbach's α coefficient (Equation (1)) between 0.80 and 1.00 indicates that the scale is highly reliable and the items are consistent with each other and measure the same property [63]. The study was found to be highly reliable since Cronbach's α coefficient was 0.891 (Table 1). The alpha values obtained when each question was removed are presented in Table 2. The number of the question removed is given in the "No" column.

Cronbach's $\boldsymbol{\alpha}$ Equation:

$$\boldsymbol{\alpha} = \left(\frac{\boldsymbol{K}}{\boldsymbol{K-1}}\right)\left(\mathbf{1} - \frac{\sum \boldsymbol{V_i}}{\boldsymbol{V_T}}\right) \quad (1)$$

Table 1. Test results.

The Number of Participants	Cronbach's Alpha Coefficient	Number of Expressions
295	0.891	30

Table 2. Alpha values obtained when questions are removed.

No	Alpha	No	Alpha	No	Alpha	No	Alpha	No	Alpha	No	Alpha
1	0.890	6	0.890	11	0.890	16	0.889	21	0.888	26	0.887
2	0.888	7	0.889	12	0.891	17	0.888	22	0.890	27	0.893
3	0.889	8	0.887	13	0.889	18	0.888	23	0.886	28	0.888
4	0.888	9	0.886	14	0.888	19	0.888	24	0.887	29	0.889
5	0.887	10	0.887	15	0.890	20	0.887	25	0.891	30	0.889

The results of the survey on the efficiency of the system applied to students are presented in Table 3. The weights of the students' answers were calculated, and it was observed that the questions were accepted minimum by 46.51%, maximum by 81.29%, and by 61.76% on average. According to the answers to the survey, it is realized that the physical ambient conditions affect the focus, health, emotions, and thoughts of students. Moreover, it is observed that students are concerned about ventilation conditions.

Table 3. Survey results.

No	Question	Score %
1	The high temperature negatively affects my focus in the lesson.	68.14
2	The low temperature negatively affects my focus in the lesson.	68.81
3	Someone walking around the classroom to adjust the ambient temperature negatively affects my focus in the lesson.	52.27
4	Constantly changing the temperature setting by the students or the teacher negatively affects my focus on the lesson.	53.56
5	The automatic control of the temperature system has a positive effect on my focus on the lesson.	70.71
6	The fact that the temperature system is not controlled automatically affects my health negatively.	46.51
7	The fact that the temperature system is individual has a positive effect on my focus on the lesson.	57.29
8	In situations where the lighting is insufficient, I get sleepy and this negatively affects my focus on the lesson.	75.66
9	In situations where the lighting is insufficient, I have visual difficulties and this affects my focus in the lesson negatively.	67.93
10	The automatic control of the lighting has a positive effect on my focus on the lesson.	68.88
11	The direct sunlight on my face or its reflection in the classroom negatively affects my focus in the lesson.	77.76
12	Excessive light negatively affects my focus in the lesson.	72.14
13	Preventing the sunlight from coming into my field of view with the automatic curtain has a positive effect on my focus on the lesson.	75.66
14	I am having trouble understanding the information the teacher writes or reflects on the board because the temperature is unstable.	46.92
15	I have trouble understanding the information that the teacher writes or reflects on the board because my perspective is not clear.	53.22
16	I am having trouble understanding the information that the teacher writes or reflects on the board due to insufficient light.	47.25
17	I disagree with my friends about leaving windows open to ventilate the classroom.	51.19
18	The wind/cold caused by keeping the windows open all the time affects my health negatively.	63.73
19	The external noise caused by keeping the windows open all the time negatively affects my focus on the lesson.	66.92
20	Not properly ventilating the classroom environment negatively affects my focus on the lesson.	62.85
21	Automatic control of the window for natural ventilation positively affects my focus on the lesson.	66.51
22	Perfume etc. in the classroom environment. Smells negatively affect my focus on the lesson.	52.54
23	The fact that the teacher's voice is not heard in the class I am in makes it difficult for me to learn.	62.37
24	The fact that the air in the classroom environment does not have enough humidity negatively affects my focus on the lesson.	53.76
25	The high humidity of the air in the classroom negatively affects my focus on the lesson.	60.07
26	Flu, COVID-19 etc. I think that infectious diseases are transmitted due to insufficient ventilation in the classroom environment.	55.53
27	The high air quality in the classroom has a positive effect on my focus on the lesson.	81.29
28	Regular temperature measurement in the classroom makes me feel comfortable in terms of COVID-19 measures.	57.69
29	Since the school is in the OIZ, I feel worried that the air coming from outside smells bad.	58.24
30	The thought that the air coming from outside can be harmful because the school is in the OIZ worries me.	57.49

Students received education in the SCI, designed according to the survey results and in line with the needs observed in the literature. The actual average test scores of students are given in Figure 15 on a position basis to represent students. It is observed that, in the SCI, the students' scores were higher and parallel with the surveys despite individual differences.

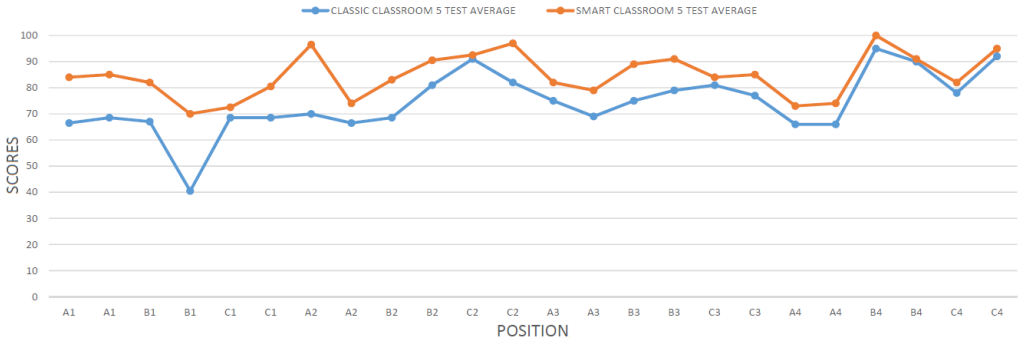


Figure 15. Average score chart of the five tests applied in classical and smart classrooms.

4. Discussion

In this study, research on the measurement and control of the physical conditions of learning environments in the literature was reviewed, and the result of a comparison between previous research and this study is given in Table 4. As can be seen, previous research has rather focused on the measurement of parameters in learning environments; the number of the measured parameters was usually 1, and a maximum of 3 parameters were measured in two studies. In experimental studies, only 1 parameter was measured with a standard measuring instrument in general. In few studies, 3 parameters were only measured but not controlled. As seen in Table 4, the number of studies involving automation and control processes on this subject, in other words, applications, is quite limited in the literature. In this limited number of studies, only one parameter was usually measured and controlled. Furthermore, the number of studies in which more than one parameter was controlled simultaneously is 2. The number of studies on temperature control is only 2. The number of model studies is also limited.

Table 4. Work comparison.

Classification	Reference No	Thermal	Lighting	Air Quality	Acoistic, Noise	Experimental	Measurement	Automation Control	Energy-saving	Financial sustainability	Model
Physical Conditions	2	✔	✔	✔	✔						
Physical Conditions	3	✔		✔							
Physical Conditions	4	✔									
Physical Conditions	5	✔		✔		✔					
Physical Conditions	6	✔				✔	✔				
Physical Conditions	7	✔		✔			✔	✔			
Physical Conditions	8	✔									
Physical Conditions	9	✔		✔			✔	✔	✔		
Physical Conditions	10	✔									
Physical Conditions	11	✔	✔		✔	✔	✔				
Physical Conditions	12	✔	✔		✔		✔				
Physical Conditions	13		✔								
Physical Conditions	14		✔			✔	✔				
Physical Conditions	15		✔								
Physical Conditions	16		✔			✔					
Physical Conditions	17		✔				✔	✔	✔	✔	
Physical Conditions	18					✔	✔				
Physical Conditions	19		✔					✔	✔		
Physical Conditions	20			✔							
Physical Conditions	21			✔							
Physical Conditions	22			✔							
Physical Conditions	23			✔							

Table 4. *Cont.*

Classification	Reference No	Thermal	Lighting	Air Quality	Acoistic, Noise	Experimental	Measurement	Automation Control	Energy-saving	Financial sustainability	Model
Physical Conditions	24						✔				
Physical Conditions	25			✔		✔					
Physical Conditions	26			✔				✔			
Physical Conditions	27			✔				✔			
Physical Conditions	28				✔	✔	✔				
Physical Conditions	29					✔	✔				
Physical Conditions	30					✔	✔				
Efficient	49					✔		✔	✔		
Efficient	50								✔		
Efficient	51								✔		
Technology	55					✔	✔	✔			✔
Technology	56									✔	✔
Smart Classroom Incubator		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

Since all parameters of the learning environment affect learning efficiency, the subject was approached holistically from two aspects in this study. First, this study incorporates hardware, software, experimental studies, case studies, and survey studies. Second, a higher number of necessary parameters were measured and controlled. For this reason and other reasons mentioned in this study, the system and the environment in which it was installed were called a smart classroom incubator (SCI). Unlike previous studies, not only methods used in educational sciences and social sciences but also engineering techniques and methods were employed effectively and in depth in the system design.

The parameters measured in this study were sound intensity, temperature, relative humidity rate, light intensity, air quality, and ambient pollution. The parameters to be controlled were temperature, automatically controlled position-based lighting, improved air quality, and ambient cleanliness. As can be seen, more parameters were measured and controlled. Moreover, temperature control, one of the most variable parameters in the environment and therefore one of the most effective parameters on human comfort, convenience, and thus performance, was studied, and control processes were individualized as the temperature level preference changes more from person to person. Lighting was adjusted according to the position, air quality was improved, and a more efficient and healthier environment was provided through UV sterilization. The sound distribution of the teacher in the classroom was measured, the sound distribution was mapped, and the sound distribution was made more homogeneous with necessary feedback. Upon analyzing the data obtained, it was observed that the sound distribution between teacher-based points decreased from a 21.1-decibel average difference value to an 11.1-decibel average difference value.

The data were transferred to the cloud system via IoT. With data-based operations, it became possible to monitor students' success and provide feedback to the relevant people. In the system's design, importance was attached to ergonomics. Unlike other studies, all the system and measurement instruments were placed in a way that would not affect the learning environment. In the system, these parameters were controlled more accurately by making use of the latest technology and methods. For sustainability, attention was paid to keeping costs low using new technologies. However, this is not the subject of this study. Therefore, it is not discussed here.

This study revealed that students' success and efficiency in education increased when the afore-mentioned ambient conditions were controlled. The average score of students studying in the SCI environment was 85, and the average score was 74 in the conventional

classroom. The high reliability of the model implemented in the study was proven by obtaining Cronbach's α coefficient of 0.891. The survey results indicate that physical ambient parameters affect students' focus, health, emotions, and thoughts.

It is expected that this study will help use energy resources more efficiently and save energy. It may also be helpful in making classroom environments, which bring together the teacher and the student, healthier, especially during the pandemic. Efficiency can be increased even more by using small-sized and new-generation sensors in such systems [64–67]. It is thought that the SCI implemented in this study and the successful results obtained may pioneer studies to be conducted for increasing the efficiency of the following educational activities.

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