Environmental measurements of classrooms at the Florida A and M University

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ABSTRACT: Classroom environment was comprehensively investigated at Florida Agricultural and Mechanical University (FAMU) in Tallahassee, Florida. The purpose of this study was first to objectively measure environmental factors of classrooms at FAMU such as thermal conditions, indoor air quality, lighting and acoustics and to ascertain if the classroom environmental factors affect academic achievement of students in the college level. This study adds to a growing body of literature that the condition of school facilities affects student achievement at the elementary, middle, and high school levels.

A total of 11 classrooms in the Architecture building and the Education building at FAMU were measured twice to represent the empty classroom and the occupied classroom by students at two different locations in each classroom. The classroom environments at the occupied condition were measured while lectures were ongoing during 2014 fall. Thermal conditions such as dry-bulb temperature, wet-bulb temperature and % relative humidity were measured to investigate thermal comfort. CO_2 concentration was measured to evaluate the indoor air quality. Light levels were measured in accordance to the style of the lectures. The background noises were measured and compared with NC curves. Room acoustical parameters such as Sound Transmission Index (Speech Intelligibility), Reverberation Time, D50, etc. were not measured at this time.

The classrooms with recent renovation showed relatively better classroom environment in all environmental factors. The background noise levels of the classrooms in the Architecture building were higher than 55dBC, whereas those in the Education building were maintained below it. The light level requirement of 430 lux established by Florida Department of Education seems not effective for the classrooms in universities where various classroom activities occur. The CO_2 concentration levels were not stable but dependent on the outdoor temperature while the temperatures were maintained in the classrooms.

KEYWORDS: Classroom Environment, CO_2 Concentration, Temperature, Lighting, Acoustics

INTRODUCTION

The quality of the school buildings forms the framework for teaching and learning, so that environmental factors such as temperature, indoor air quality, lighting and acoustical control influence student behavior and academic achievement (Edwards 2006, Lumpkin 2013). Proper temperature, indoor air quality, lighting and acoustics have been shown to improve the quality of the learning environments in schools and may lead to higher student achievement (Schneider, 2002). Inadequate indoor air quality in schools is linked to higher health care costs, increased absenteeism, and lower test scores. At the elementary, secondary, and high school level, the condition of classrooms is more correlated to student performance than the combined influences of family background, socioeconomic status, school attendance, and behavior (Lyons 2001).

High student achievement, retention, and graduation rates are the primary goal of educators and a multi-cultural global economy benefits from its attainment. College and university classrooms provide the physical spaces where teaching and learning occur that help fulfill this goal. Park and Choi (2014) stated "the classroom is one of the crucial physical services that a university provides to support students' learning" (p. 756). Most of the literature investigating the relationship between the condition of classrooms and student academic achievement exist at the elementary, secondary, or high school level. Limited research has examined the impact of classroom environmental conditions on student academic achievement at the college or university level.

The purpose of this study was first to investigate classroom environments measuring environmental factors and secondly to ascertain if the environmental factors influence the academic achievement as measured by performance on exams. Students' academic performance would be compared in college classrooms at Florida A&M University (FAMU) after the final grade is posted. In this paper, the objective environmental measurements would be performed and addressed.

1.0 BACKGROUND LITERATURE: IMPORTANCE OF CLASSROOM ENVIRONMENT

There has been scientific research investigating adverse effects of indoor environments on human health. The environments would be thermal environment, indoor air quality, visual environment, acoustic environment, etc. Many researchers also have been studying the relationship between the indoor environments and the health and the performance of people. Researchers determined the Sick Building Syndrome (SBS) and Building Related Illness (BRI) which were associated with poor indoor air quality of commercials and institutional buildings in the 1790s (Kreiss 1989). When it comes to indoor air quality, higher indoor CO_2 concentrations indicating less outdoor air ventilation were associated with students' lower scores on a computerized test of reaction time (Myhrvold et al. 1996). There were research that have demonstrated a quantitative relationship between work performance in office environments and ventilation (Seppänen et al. 2006; Shaughnessy et al. 2006; Bear 1993). Earthman pointed out that increases in temperatures in the workplace tends to decrease workers efficiency and increases the risk of work related accidents (Earthman 2002). As a result, proper control of the thermal environment is needed in the workplace. Daylighting plays an important part in the indoor environmental quality and has a positive effect on an occupant's perception of productivity and performance (Heschong et al. 1999). Researchers have been studying the negative effects of ambient noise and poor room acoustics on students' performance such as memory, educational progress, reading scores, etc. (Bradley and Sato 2008; Crandell et al. 1995; Evans and Maxwell 1997).

1.1. Thermal condition

Good thermal environment of a classroom is very important to be achieved for students' academic achievement. Many researchers have studied thermal conditions in the business and industrial workplace and the overall conclusion of these research was that increases in temperatures in the workplace tend to decrease workers efficiency and increase the risk of work related accidents (Earthman 2002; Uline 2006). These studies have provided some of the motivation for research efforts on the influence the thermal quality of the classroom has upon students. As a result, proper control of the thermal environment is necessary for students' academic satisfaction.

In addition, researchers have been studying the temperature range associated with better learning for several decades. Harner found that the best temperature range for learning, reading and math is 20°C (68°F) to 29°C (84°F) and that the ability to learn theses subjects is adversely affected by temperature above 23°C (74°F) (Harner 1974). As temperature and humidity increase, students report greater discomfort, and their achievement and task-performance deteriorate as attention spaces decreases. Furthermore, there is a general thermal comfort suggested by ASHRAE Standard 55-2013. It considers amount of clothing during summer and winter aside from dry-bulb temperature and quantity of moisture in air, although it does not take radiant heat energy into account. In sum, in order to determine thermal comfort of classroom environment, dry-bulb temperature, wet-bulb temperature and relative humidity would be measured (Harner 1974; Mendell and Heath 2005).

1.2. Indoor air quality

Recent independent studies have documented that the quality of indoor air has a significant and positive influence on the productivity of office workers (Clements-Croome et al. 2008; Kajtár et al. 2006; Myhrvold et al. 1996) and that there is a linear relationship between ventilation rate and test scores for the range of schools with ventilation rates below the recommended minimum. Some of the research showed some evidence that can link low ventilation rates with reduced attendance (Shendell et al. 2004) and with the students' school work performance (Wargocki et al. 2005). Mendell and Heath[18] also reviewed evidence that certain conditions commonly found in US schools have adverse effects on the health and the academic performance of many of the more than 50 million US school children (Mendell and Heath 2005). One of the first symptoms of poor ventilation in a building is a buildup of CO_2 caused by human respiration. When CO_2 levels reach 1000 parts per million (ppm) which is about three times what is normally found in the atmosphere, headaches, drowsiness, and the inability to concentrate can occur. Myhrvold et al. found that increased CO_2 levels in classrooms owing to poor ventilation decreased student performance on concentration tests and increased students' complaints of health problems as compared to classes with lower CO_2 levels (Myhrvold et al. 1996). Thus, the CO_2 concentrations can be translated into ventilation rates assuming a source term for CO_2 generation, and assuming CO_2 concentration had reached steady state in the room based on ASTM D 6245, and will be measured.

1.3. Lighting

Lighting and daylighting play an important role in the indoor environmental quality and have a positive effect on an occupant's perception of productivity and performance (Heschong et al. 1999; Xue 2002). Classroom lighting plays a particularly critical role in student performance (Philips 1997). Video projectors and smart boards are actively used in a large portion of the classes in universities these days. The variation of illuminance with and without the use of projectors would provide different visual environment and it would be worthy to measure the lighting level variation during the lecture.

1.4. Acoustics

Acoustics have been shown to have an impact on student learning. There are many consistent and convincing evidence that acoustics links to learning (Cash 1993; Earthman 2004; Hines 1996). In general, good acoustics are fundamental to good academic performance. Earthman and Lemasters reported three key findings that higher student achievement is associated with schools that have less external noise, that outside noise causes increased student dissatisfaction with their classrooms, and that excessive noise causes stress in students (Earthman and Lemasters 1998). Crandell et al. and Nabelek and Nabelek reviewed the literature linking the acoustical environment in a classroom to the academic achievement of children and have linked levels of classroom noise and reverberation to reading and spelling ability, behavior, attention, concentration, and academic achievement in children (Crandell et al. 1995; Nabelek and Nabelek 1994). Evans and Maxwell examined 100 students enrolled in two New York City schools, one of which was in the flight path of an airport. The students exposed to the air-traffic noise scored as much as twenty percent lower on a reading test than children in the other school (Evans and Maxwell 1997).

2.0 RESEARCH GOALS AND OBJECTIVES

2.1. Research goals

The primary goal of the research is to contribute to creating a learning environment for students at the FAMU by investigating the physical and architectural properties associated with better classroom environments such as thermal conditions, indoor air quality, lighting and acoustics. This will eventually lead to efficient students performance. In this research, the physical and architectural properties of the classroom would only be investigated over classrooms at the FAMU, although students' social dynamics, learning climate, teachers behavior and attitudes, etc. would be all the possible factors associated with student's performance as well.

The long term goal is to develop architectural design guideline for university classrooms. In the sense that video projection and sound systems are actively used in the university classroom, different design guidelines from K - 12 public schools would be required especially for visual and acoustic comfort during the classes. The design guideline should reflect the possible findings related to the environmental and architectural features of the classroom environments.

2.2. Research objectives

In order to achieve the long term goals, there would be three research objectives in this research. First, environmental factors of the classrooms such as thermal conditions, indoor air quality, lighting and acoustics would be measured by objective means. Classroom environments would be a measure of the cumulative effects of them. Many researches, however, provided not enough objective data to evaluate the classroom environment. Instead, they rather used questionnaires to determine the physical qualities of the classrooms rated by the occupants. In this research, the physical properties of the classroom environments would be objectively measured to determine each environment and the comprehensive conditions of the classrooms.

Second, statistical approach would be used to test the possible effects of classroom environments on students performance. The objective measurement data of the classrooms would be compared with the grades of the students by various statistical methods such as factor analysis, liner regression, paired t-test, etc., in order to find important environmental factors that impact students' academic performance.

Lastly, to validate the effects of classroom environments on students performance, some of the classrooms measured would be sampled and treated for improvement of the environmental factors. This validation may be performed during the 2015 summer or fall after the improvement of the classroom.

In this paper, only the objective environmental measurements of classrooms at the FAMU would be performed and addressed.

3.0 METHODOLOGY

3.1. Objective environmental measurement

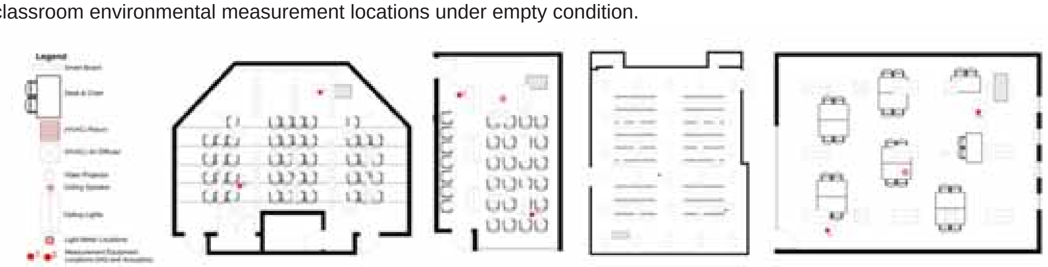
The environmental qualities of classrooms at the FAMU were measured by objective means. The TSI-7545 indoor air quality meter was used to measure thermal properties such as dry-bulb temperature (°C), wet-bulb temperature (°C) and relative humidity (%) and carbon dioxide concentration (CO_2) as a means for indoor air quality. The outdoor CO_2 level was not measured but assumed that it is approximately 300 ppm. This would limit the indoor CO_2 level in 1000 ppm, because the indoor level should not be 700 ppm greater than the outdoor level according to ASHRAE 62.1-2013. Light levels (lux) were measured by the Extech LT-300 light meter. Background noise levels (dBC) were measured by the Rion NL-52 Class 1 sound level meter and compared with Noise Criterion (NC) curves. Two sets of environmental measurements were conducted at two separate locations in each room. One set of measurement was to measure the environmental factors of the empty classrooms and the other was to measure when the classrooms were occupied by students. A total of 11 classrooms including 4 classrooms in the Walter Smith Architecture building (henceforth Architecture building) and 7 classrooms in the Gore Education Complex building (henceforth Education building) were measured.

The classrooms were measured at least twice to represent the classroom environment without students and with students. Thermal conditions such as dry-bulb temperature, wet-bulb temperature and % relative humidity were measured to investigate thermal comfort in each room. CO_2 concentration was measured to evaluate the indoor air quality as a replacement of ventilation rate. Light levels were measured on the desk level with all the lights turned on for the empty condition and in accordance to the lectures for the occupied condition. The background noises were measured in the 1.2 m above the floor and compared with NC curves. The sound pressure levels were measured to see the general sound pressure levels during the lecture. Room acoustical parameters such as Sound Transmission Index (Speech Intelligibility), Reverberation Time, D50, etc. were not measured at this time.

3.2. Architecture building

The Architecture building has only four classrooms while there are many open design studios and office rooms. The four classrooms, ARC111, ARC112, ARC 121 and ARC233, are all different in size to accommodate a various style of lectures from small size lecture to large size seminar and daylight is not available at all classrooms. Although ARC233 has a glass wall, the top lighting in the north atrium of the building is blocked by the parapet on the third floor and then enters the room in low light level. The room temperature is monitored at the thermostat located in the room and controlled by only the central plant personnel. There are multiple supply air diffusers while there is no specific return grilles in the classrooms. The regulated air is returning through hallways and the air plenum above each room. There are a video projector, a projection screen, a sound system, video players, etc. in each room (see Table 1).

Table 1: Floor plans of the four classrooms in the Architecture building showing floor areas, room volumes, and classroom environmental measurement locations under empty condition.



Room	ARC 111	ARC 112	ARC 121	ARC 233
Area (m² (ft²))	81.3 (875)	49.2 (529)	260.1 (2,800)	104.1(1,120)
Vol. (m³ (ft³))	372 (13,125)	150 (5,290)	951 (33,600)	389 (12,320)

The occupied condition of the classroom, ARC 112, was not measured, because all classes in ARC 112 has been moved to dean's conference room in the Architecture building due to technology update in 2014 fall semester.

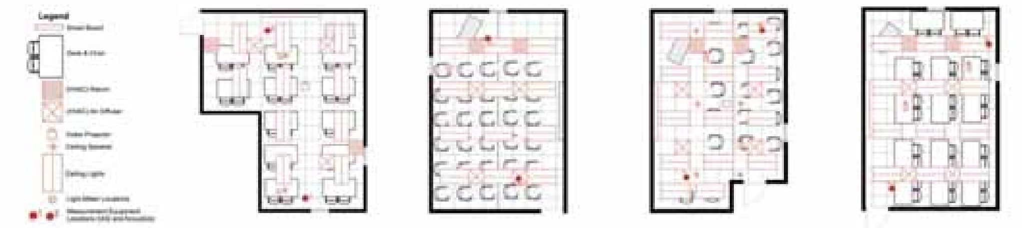
3.3. Education building

The Education building consists of three wings. The classrooms on the first floors of the A and B wings are used as classrooms. The classrooms were renovated 4 years ago. The classrooms sampled were those that the instructors permitted the environmental measurements during the lecture. A total of 7 instructors were approved to the research. Their lectures were held in the GEC A107, A108, A110, A112, B101, B103, and B104. The environmental measurements were performed when there was no class in the Education building as empty conditions.

The classrooms in the Education building are similar in size, color, finishes, furniture, etc. There are 3 or 4 supply air diffusers and 2 return grilles each classroom. The dry-bulb temperature is monitored by a thermostat on the side wall and maintained by the central plant personnel. Each room has 2 (0.6m x 2.7m) glasses on the exterior walls which provide daylight. The windows, however, were not operable and not delivering adequate light level because of the small size and inefficient locations which could not reach the other side of the room (see Table 2). The electric lighting fixtures (0.6m x 1.2m) were well distributed over the classrooms and has three separate switches providing 6 different lighting modes and light levels on the desk to accommodate various types of lectures.

Only 5 classes of them, however, were observed and measured during the lecture due to the unexpected circumstances, which resulted in a total of 5 classrooms (GEC A108, A112, B101, B103 and B104) could be measured with students occupied.

Table 2: Floor plans of the four types of classrooms in the Education building showing floor areas, room volumes, glazing and classroom environmental measurement locations under empty condition.



Room	GEC A107, A108	GEC A110, B101	GEC A112, B103	GEC B104
Area (m^2 (ft^2))	45.5 (490)	44.6 (480)	44.6 (480)	44.6 (480)
Vol. (m^3 (ft^3))	138.8 (4,900)	135.9 (4,800)	135.9 (4,800)	135.9 (4,800)

4.0. RESULTS AND DISCUSSIONS

4.1. Empty conditions

A total of 11 classrooms were measured when there is no students other than experimenters during the weekdays. The averaged thermal conditions were well maintained within the thermal comfort zone specified by ASHARE Standard 55-2013 (see Table 3). Light levels with all the electric lighting fixtures on, on the other hand, ranged from 204.4 lux to 397.2 lux in the classrooms in the Architecture building, while all the classrooms in the Education building showed light levels above the State Requirement for Education Facilities established by Florida Department of Education which is 430 lux (40 fc). The background noise levels of classrooms are limited to be less than 55 dBC (ANSI/ASA S12.60-2010/Part 1) and the recommended NC values are NC-30 to NC-35. The classrooms at the Architecture building showed higher background noise levels than the both recommendation, whereas those in the Education building showed lower background noise levels (see Fig.1).

Table 3: The averaged thermal conditions (dry-bulb temperature (DBT), wet-bulb temperature (WBT) and relative humidity (%)), CO_2 concentration (ppm), light levels, Noise Criteria (NC) and overall background noise levels of the 11 classrooms when there is no students in the classrooms.

Classroom	DBT (°C)	WBT (°C)	% RH	CO_2 (ppm)	Light level (lux)	NC	Overall (dBC)
ARC 111	24.9	16.4	42.0	1076	203.4	39	72.5
ARC 112	24.9	16.4	41.9	1020	-	39	63.9
ARC 121	22.4	16.2	52.2	583	375.7	36	60.6
ARC 233	22.3	15.4	48.5	627	397.2	31	62.7
GECA 107	25.6	11.2	21.5	517	428.4	27	48.9
GECA 108	22.3	11.6	24.4	537	599.5	33	51.5
GECA 110	23.0	11.6	22.1	500	784.7	32	53.9
GECA 112	22.8	11.6	22.8	509	447.8	32	51.3
GECB 101	23.1	15.5	44.7	609	578.0	27	49.7
GECB 103	21.3	10.4	21.8	477	532.8	27	53.2
GECB 104	21.0	10.6	24.0	503	742.7	27	52.0

4.2. Occupied conditions

A total of 9 classrooms (ARC111, ARC121, ARC233, GEC A108, A112, B101, B103, and B104) were measured under occupied condition when actual lectures were on going. The thermal conditions were not significantly different from when the classrooms were empty. However, there was a tendency that the dry-bulb temperature and wet-bulb temperature increased while relative humidity decreased over time with students occupied. Although the difference of thermal conditions between the times when the lecture began and ended was not significant, the CO_2 concentration levels significantly increased over the class time period with students occupied in the classroom (see Fig.2 and Table 4). The delta 'Δ' indicates the differences of each factor between the times when the lecture began and ended.

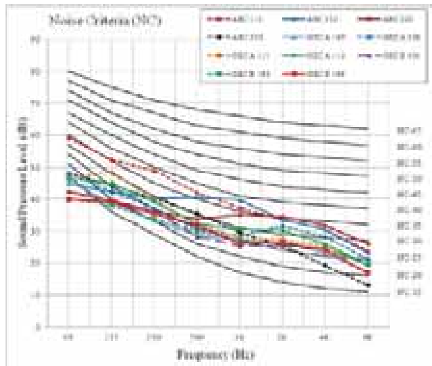


Figure 1: Background noise levels of the 11 classrooms and the noise criteria contours: noise criterion of a background noise level is defined by the noise criteria contours.

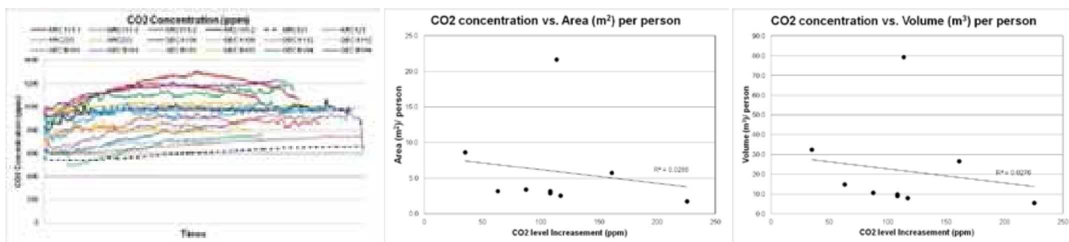


Figure 2: CO_2 concentration levels in the 7 classrooms when the lectures were ongoing (left). The CO_2 concentration levels were measured at two different locations. CO2 concentration increase was also compared with floor area (m^2) per person (middle) and with room volume (m^3) / person (right).

In order to scrutinize the effects of students' perspiration, the CO_2 concentration levels were also compared with two values: floor area (m^2) per person and room volume (m^3) per person. The number of students in this case was not the number of seats but the number of students who attended the lecture during the environmental measurement. The reason that there is one peak in the right chart (Fig.2) is that the room, ARC 121, is relatively bigger than other classrooms measured, but there were only 12 students presented at that time. There was a tendency that CO_2 concentration level did not increase much in the classrooms that have larger room volumes per person than those with less room volumes per person (see Table 4).

Table 4: The averaged thermal conditions (dry-bulb temperature (DBT), wet-bulb temperature (WBT) and relative humidity (%)), CO_2 concentration (ppm), light levels, Noise Criteria (NC) and overall background noise levels of the 7 classrooms when they were occupied by students. The ARC 111 measured twice for two different classes in two different times. The delta 'Δ' indicates the differences of each factor between the time when the lecture began and the time when it ended.

Classroom	DBT (°C)	WBT (°C)	RH (%)	CO_2 (ppm)	Δ DBT (°C)	ΔWBT (°C)	RH (%)	ΔCO_2 (ppm)	Floor Area (m^2)	Vol. (m^3)	N. of Student	m^2 /per.	m3 /per.
ARC 111-1	22.2	14.2	40.3	683	0.1	2.8	-2.7	161	81.3	372	14	5.8	26.6
ARC 111-2	22.1	16.0	53.9	1140	0.0	-1.9	-0.1	63	81.3	372	25	3.3	14.9
ARC 121	23.2	16.3	48.9	642	0.9	0.3	-2.7	113.5	260.1	951	12	21.7	79.3
ARC 233	23.1	16.3	49.7	988	0.0	-0.1	-0.6	35	104.1	389	12	8.7	32.4
GECA 108	22.8	15.9	48.8	970	0.9	0.3	-2.3	108	45.5	136	14	3.3	9.7
GECA 112	22.4	15.8	50.2	914	-0.1	-0.1	-0.1	87.5	44.6	139	13	3.4	10.7
GECB 101	23.3	17.3	55.2	885	-0.1	0.4	3.3	108	44.6	136	15	3.0	9.1
GECB 103	21.8	14.2	42.6	740	1.3	0.6	-2.5	117	44.6	136	17	2.6	8.0
GECB 104	24.2	16.6	46.6	1120	2.8	0.6	-10.6	225.5	44.6	136	25	1.8	5.4

In addition, it was observed that the CO_2 concentration level of ARC 111 showed 457 ppm difference between two measurements. The measurement, ARC 111-1, was measured at 9am in November 4, 2014 and the ARC 111-2 was measured at 11am in November 6, 2014. Interestingly enough, the CO_2 concentration in the ARC 233 measured at 5:30pm in November 6 were also showed 361 ppm higher than that conducted in October 30, 2014. In this sense, it is worthy to look at the CO_2 concentration levels of all classrooms by dates (see Table 5) to see if there were specific dates with high CO_2 concentration overall.

As shown the table, the four dates (10/30, 11/6, 11/12, and 11/13 in 2014) showed high CO_2 concentration levels. Based on the weather data, outdoor daily average dry-bulb temperature was suddenly dropped from 21.1 °C (70 °F) in October 27, 2014 to 8.9 °C (48 °F) in November 2, 2014. This might change the setting of air handling units in the buildings to heating the supply air, which in turn might change the portion of fresh air in the air handling units. Therefore, it is possible to say that the CO_2 concentration is somehow associated with the way that an air handling unit regulates the amount of fresh air and return air based on the exterior dry-bulb temperature.

Table 5: CO2 concentration levels of all 11 classrooms by measurement dates. Shaded areas are showing higher CO_2 levels.

Classroom	10/9	10/13	10/30	11/4	11/6	11/10	11/12	11/13	11/14	11/17	12/3
ARC 111	-	554	1076	683	1140	-	-	-	-	-	-
ARC 112	-	575	1020	-	-	-	-	-	-	-	-
ARC 121	698	-	-	-	-	-	-	642	-	-	-
ARC 233	-	-	627	-	988	-	-	-	-	-	-
GECA 107	-	-	-	-	-	-	-	-	517	-	-
GECA 108	-	-	-	-	-	-	-	970	537	-	-
GECA 110	-	-	-	-	-	-	-	-	500	-	-
GECA 112	-	-	-	-	-	-	914	-	509	-	-
GECB 101	-	-	-	-	-	-	-	-	609	885	-
GECB 103	-	-	-	-	-	740	-	-	-	-	477
GECB 104		-	-	-	-	-	-	1120	503	-	-

The light levels of classrooms measured were varied because of the various style of lectures in the classrooms, although the electric lighting fixtures were evenly distributed across the rooms. There were lighting switches in each classroom to control the electric lighting fixtures creating three to four different levels of lighting depending on the lecture style. The lighting level in the middle of the room GEC B101 was measured at 781.5 lux (73.6 fc) right under the electric lighting fixture with daylight and all the lighting fixtures on, but it was measured at 33.4 lux (3.1 fc) with all the lights off. The lighting level was set at 578 lux (53.7 fc) during the class when the students used the smart board and handout materials for their presentations but the quality of the video projection on the smart board was not clear enough at that time, because the light level of the room was too bright for the images projected on the smart board. The classroom, ARC 121, on the other hand, has no daylight. The light level of the classroom was measured 29 lux (2.7 fc) with the emergency lighting fixtures. It was set at 338 lux (31.4 fc) for the presentation and 363.8 lux (33.8 fc) with all the lights on.

CONCLUSION

A total of 11 classrooms in the Architecture building and the Education building at the Florida A and M University were measured in regards to classroom environmental factors such as thermal conditions, CO_2 concentration, lighting levels, and background noise levels. The classrooms with recent renovation (the Education building) showed relatively better classroom environment in all environmental factors. Especially, the background noise levels of the classrooms in the Architecture building were higher than 55dBC which is recommended by ANSI/ASA S12.60-2010/Part 1, whereas those in the Education building were maintained below it. The light level requirement (430 lux (40 fc)) established by Florida Department of Education, on the other hand, seems not effective to be adapted to the classrooms in universities. The activities of the classrooms at FAMU varied from writing to presentation which would require different light levels as well as good quality of video projection. The CO_2 concentration levels increased by students' perspiration during the class period. The CO_2 concentration levels were not stable but significantly changed even in the same classroom (ARC 111) at different times and dates. This would be possibly because of the air handling unit that mixes return air and Oxygen rich fresh air differently under various weather condition while it maintains relatively stable dry-bulb temperature in the classrooms. Therefore, apart from dry-bulb temperature, it would be necessary to monitor CO_2 concentration to provide students with better indoor air quality resulting in better academic achievement.

FUTURE STUDY

As a following study, the environmental measurement data will be statistically analyzed and compared with the final grades of the students who have studied in the classroom measured. More detail analyses of light level and acoustics are required to study adequate levels of lighting and speech intelligibility for various class activities.

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