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CORRELATION BETWEEN OCCUPANT COMFORT AND ENERGY SAVING AT UNIVERSITY BUILDING: CASE STUDY OF YASAR UNIVERSITY BUILDINGS

ŞADİYE BİRCE ONGUN

THESIS ADVISOR: ASSIST. PROF. HACER ŞEKERCİ ÖZTURA
CO-ADVISOR: ASSOC. PROF. NURDAN YILDIRIM

ELECTRICAL AND ELECTRONICS ENGINEERING

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We certify that, as the jury, we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Jury Members:	**Signature:**
Assist. Prof. Hacer ŞEKERCİ ÖZTURA Yaşar University	....
Assoc. Prof. Nurdan YILDIRIM Yaşar University	....
Assist. Prof. Emrah BIYIK Yasar University	....
Assist. Prof. İlker KAHRAMAN Yasar University	....
Prof. Sait SOFUOĞLU Izmir Institute of Technology	....

Prof. Cüneyt GÜZELİŞ

Director of the Graduate School

ABSTRACT

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Ongun, Şadiye Birce
Msc, Electrical and Electronics Engineering
Advisor: Assist. Prof. Hacer ŞEKERCİ ÖZTURA
Co-Advisor: Assoc. Prof. Nurdan YILDIRIM
May 2020

The aim of this study is to examine the parameters affecting energy consumption and indoor air quality in university buildings and to develop methods for energy improvements. Within the scope of the study, examinations were carried out in selected classes in two different buildings of Yaşar University in Izmir. In these classes, temperature, CO_2 concentration and window opening data were measured and recorded at 15-minute intervals for 1 year. During the measurement process, energy consumption data of buildings, working conditions of HVAC system and active class occupancy data were collected. Analyzes were made on the change of indoor air quality for the use of the measurement data collected during the lessons and exam periods. In these analyzes, the effect of occupancy and window opening on CO_2 concentration and indoor air temperature was investigated. The volume flow rate required to not exceed the CO_2 concentration, which is defined in the standards, has been proposed. For the sample classes selected from both buildings, the ACH values to achieve CO_2 concentration below the limit value were found as 2.2 h^{-1} and 2.8 h^{-1} for Y and T buildings, respectively. In addition, the effect of outdoor air temperature and HVAC operating conditions on energy consumption has been studied. It has been observed that approximately 20% energy savings can be achieved by changing the HVAC operating conditions in the investigated building.

Key Words: HVAC systems, CO_2 concentration, buildings, thermal comfort, window opening, energy consumption

ÖZ

ÜNİVERSİTE BİNALARINDA KULLANICI KONFORU VE ENERJİ TASARRUFU ARASINDAKİ KORELASYON: YAŞAR ÜNİVERSİTESİ BİNASI İÇİN ÖRNEK İNCELEME

Ongun, Şadiye Birce
Yüksek Lisans, Elektrik Elektronik Mühendisliği
Danışman: Dr. Öğr. Üyesi Hacer ŞEKERCİ ÖZTURA
Yardımcı Danışman: Doç. Dr. Nurdan YILDIRIM
Mayıs 2020

Bu çalışmanın amacı, üniversite binalarında enerji tüketimine ve iç hava kalitesine etki eden parametreleri incelemek ve enerji iyileştirme yöntemleri geliştirmektir. Çalışma kapsamında, İzmir'de Yaşar Üniversitesi'ne ait iki farklı binada seçilen sınıflarda incelemeler yapılmıştır. Bu sınıflarda 1 yıl boyunca sıcaklık, CO_2 konsantrasyonu ve pencere açıklığı verileri 15 dakikalık aralıklar ile ölçülmüş ve kaydedilmiştir. Ayrıca ölçüm süreci boyunca, binaların enerji tüketim verileri, HVAC sisteminin çalışma koşulları ve aktif sınıf doluluğu verileri toplanmıştır. Toplanan ölçüm verileri ile sınıfların ders ve sınav dönemlerindeki kullanımları için iç hava kalitesinin değişimi hakkında analizler yapılmıştır. Bu analizlerde doluluk ve pencere açıklığının CO_2 konsantrasyonu ve iç ortam hava sıcaklığı üzerindeki etkisi araştırılmıştır. Standartlarda tanımlanan CO2 konsantrasyonunu aşmamak için gereken hava debisi önerilmiştir. Her iki binadan seçilen örnek sınıflar için, CO_2 konsatrasyonunun sınır değerin altında kalmasını sağlayacak ACH değerleri Y ve T için sırası ile 2.2 h-1 ve 2.8 h-1 bulunmuştur. Ayrıca, dış hava sıcaklığı ve HVAC çalışma koşullarının enerji tüketimi üzerindeki etkisi araştırılmıştır. HVAC işletim koşullarını değiştirerek incelenen binada yaklaşık %20 enerji tasarrufu sağlanabileceği görülmüştür.

Anahtar Kelimeler: iklimlendirme sistemleri, CO_2 yoğunluğu, binalar, ısıl konfor, pencere açıklığı, enerji tüketimi

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Şadiye Birce Ongun

İzmir, 2020

TEXT OF OATH

I declare and honestly confirm that my study, titled "Correlation between Occupant Comfort and Energy Saving at University Building: Case study of Yasar University Buildings" and presented as a Master's Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Full Name

Signature

Sadiye Birce ONGUN

B. Ongun

July 22, 2020

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

ACH	Air Change Rate
AHU	Air Handling Unit
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
CO_2	Carbon Dioxide
HVAC	Heating, Ventilating and Air Conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
PMV	Predictive Mean Vote
VRF	Variable refrigerant flow

SYMBOLS:

A	Area [m^2]
ACH	Air Change Rate [h^{-1}]
C(t)	Concentration of CO_2 at t [ppm]
C_{ex}	Outdoor carbon dioxide concentration [ppm]
C_0	Initial CO_2 in a zone [ppm]
G	Generation rate of CO_2 [m^3/h]
n	Air Change Rate [h^{-1}]
Q	Volume flow rate into a zone [m^3/h]
t	Time [sec]
U	Heat transfer coefficient [W/m^2K]
V	Volume of the zone [m^3]

CHAPTER 1
INTRODUCTION

In recent years, energy production and consumption are among the most important issues of developed countries (Romano et al., 2017). Continuously developing industrial technologies have increased the need for energy. Therefore, reducing unnecessary consumption of energy and increasing energy efficiency is on the agenda of many countries (Fumo et al., 2010).

According to the studies, the units that consume the most energy in a campus are buildings. It is seen that more than 40% of the total energy consumed in Europe is consumption originating from buildings (Y. Li et al., 2017). For this reason, increasing energy efficiency in buildings is one of the most important factors in reducing energy consumption. Minimizing the energy consumed by buildings is essential for energy sustainability (Walker et al., 2017).

HVAC systems constitute approximately 50% of the energy consumption in buildings and this rate is expected to increase gradually (Yang et al., 2019). Therefore, it has become an important issue to reduce the energy consumption of HVAC systems and increase the working efficiency.

On the other hand, the energy consumption of buildings largely depends on the criteria used for the indoor environment (Olesen, 2007). These criteria also greatly affect user comfort. Accepting the user factor as an input is an important step in energy studies. As can be seen in many studies, information such as user health and environmental comfort is frequently mentioned in researches (Theodosiou & Ordoumpozanis, 2008).

Indoor environmental quality (IEQ) depend on many variables. These variables are temperature, relative humidity, CO_2 concentration, air flow rate, occupancy, etc. (Almeida et al., 2014) these criteria significantly affect the health, comfort and performance of users. Indoor air quality (IAQ) is expressed as the temperature, humidity, ventilation and chemical substances of indoor air in non-industrial buildings such as schools, offices and hotels (Brown, 2019). In today's cities, Indoor Air Quality (IAQ) is an important factor because people spend most of their time in buildings (Santamouris et al., 2007). The time spent in buildings may differ for individuals. In addition, individuals are mostly in the buildings for accommodation, education and work purposes. Factors affecting IEQ also significantly affect the energy consumption of the building, so they are the elements to be considered in the design and operation process. However, most of the buildings are designed or operated inefficiently in terms of energy sustainability (Y. Li et al., 2017).

In general, insulation and comfort tests that should be applied in the early stages of building construction are ignored. Due to the high cost, insulation applications are lacking in buildings. These negligence brings different results depending on the intended use of the building. Energy efficiency negligence in residential buildings poses minor problems. However, in public buildings, this situation may causes too much energy waste.

Educational buildings (school buildings and university campus buildings) are structures that require more attention in terms of indoor air quality and energy consumption compared to other buildings (Allab et al., 2017). These structures have a higher number of users compared to home and office buildings (Chithra & Nagendra, 2012). There is a direct ratio between the number of users and energy consumption. Controlling comfort conditions in spaces with more than a certain number of people is a process with many parameters.

IAQ and thermal comfort are the important parameters that affect the productivity and work efficiency of users. It is especially important for students to provide these conditions in educational buildings. Because IAQ parameters are of great importance to increase students' attention, perception and learning levels (Özdamar & Umaroğullari, 2018).

As in the study of (Rospi et al., 2017), many studies have been done to evaluate the indoor environment quality of the classrooms. These studies are often supported by the official authorities in the country where the case study is located. When energy management is applied in buildings, energy consumption values and operating costs can be reduced (Y. Li et al., 2017). In order to perform energy audit, IAQ parameters must be measured and monitored regularly.

Devices mounted on the wall with sensors are generally preferred for these measurements. Devices can be taken to environments manually and measurements can be made within a certain period of time. However, this option is not suitable for regular and precise tracking. The most up-to-date measurement method that can be used is to collect data on fixed sensor devices placed in the locations. These devices have a common cloud system and all data can be stored there.

Inorganic gas particles (CO, NO_2, O_3), volatile organic compounds, particulate matter and organic gas pollutants are indoor air pollutants in school buildings. Therefore, providing fresh air through ventilation is essential for indoor environmental quality (IEQ) (Ekren et al.,2017). High CO_2 concentration can negatively affect people's perception and cause health problems (Krawczyk et al., 2016). However, when (Dias et al., 2016, Almeida et al., 2014, Dias Pereira et al., 2014) studies are examined, it can be seen that in many schools the CO_2 concentration exceeds the value specified in the standards such as ASHRAE and ISO7730.

Following the detailed literature study, the general monitoring and calculation definitions were introduced in Chapter 3. In Chapter 3, the purpose of the study, physical & technical features and operational parameters of the selected buildings are presented. Subsequently, methodology is described in Chapter 4. Assumptions, data analysis and calculation methods are mentioned. The relevant standards and the PMV value, which is one of the evaluation criteria, are mentioned. Then, in chapter 5, the results and findings that examine indoor air quality in educational buildings are shown. Detailed data analysis of the measurements is presented. The results of the calculation of the CO_2 concentration value and the survey studies were evaluated. Finally, in the conclusion section, the originality and importance of this study about efficiency is mentioned. Suggestions to increase energy efficiency in building types that are the subject of the research are presented. In addition, discussions were made on future studies at national and international scale.

CHAPTER 2
LITERATURE REVIEW

In this section, studies involving occupant comfort and energy consumption in the literature are examined. These studies were examined in indoor air quality (IAQ), temperature, occupancy, energy consumption, HVAC system operation and window opening condition categories. The studies reviewed are based on the ASHRAE standard. In addition, some studies were based on their country's own energy and comfort standards (STN, ISO, etc.). Detailed information about these standards is presented in Chapter 3.

In Portugal, where HVAC systems in schools can be shut down to reduce energy consumption, Dias et al. presented a study to examine indoor air quality in renewed classrooms. Their aim was to increase energy efficiency while maintaining comfort conditions in the classroom. For this reason, they recorded the energy consumption of the classes and measured some variables such as air temperature, relative humidity, air velocity, and CO_2 concentration of the indoor environment. They made these measurements on average every 2 weeks and completed the study with a questionnaire for students. They chose two classes from each school in 6 different parts of Portugal. They followed the classes for 2-3 weeks and recorded each data every 60 seconds. They interpreted the energy use per student in a year from the energy consumption data. As a result of their measurements, they did not find a sufficient correlated ratio between the days of heating and energy consumption. Therefore, they decided that energy performance should not be evaluated according to climatic conditions. When the indoor air temperatures were evaluated, the authors observed that they did not go far beyond the standard. In CO_2 concentration, the results were worse than those required values in the standard. However, the percentage of dissatisfaction is not very high. Due to the energy cost, HVAC systems are generally closed. Therefore, a proposal was made to ventilate the classes between lecture hours to reduce CO_2

concentration (Dias et al., 2016).

A university building in France has examined by Allab et al. The aim of the study is to create a procedure for improving energy efficiency and indoor air quality. Within this scope, a case study was carried out by selecting the building of the engineering faculty in Paris. The building has air handling system and a heating floor system. In order to find energy consumption, the building's 2 year electricity and gas bills have collected. There are 3 condensing gas boilers in the building to produce thermal energy. Each has a capacity of 1100 kW. There are both mechanical and natural ventilation in the offices examined. The measurements made in the offices are as follows:

- Indoor air thermal conditions
- Air flow rate
- Window aperture

Also, the building was modeled in the TrnSys program and simulated. Heat transfer coefficient (U-value) was found and used in the simulation with calculations made by measuring the internal and external temperatures of the wall. In addition, the HVAC system has turned off for 3 days when there were no users and the necessary measurements were taken to model the building. Considering the simulation and experimental results, it is seen that there was a maximum deviation of 1 ^{o}C in the indoor air temperature estimation. Annual general energy consumption has been found as 480 kWh/ (m^2yr) and this had been observed to be 2 times higher compared to other works of literature. As an energy-saving method, the heating floor system had operated with low-temperature water from evening hours until the morning. When the comfort conditions were evaluated, it had observed that there was overheating in the environment. In addition, it was found that indoor air quality was not sufficient according to the research. Considering the increase in temperature, it can be explained that there is a need for ventilation in the environment. In general, it has been observed that systems are not used in energy-efficiency mode and always operate at maximum capacity. As a solution to these problems, a more effective energy tracking system should be made and systems should not be operated when environments are not used. The ventilation system should work better to reduce the temperature rise and ensure air quality, especially where there are many users. If the offices are used by limited people, the exact opposite situation of the mentioned above is valid. As a result, it was proposed to upgrade the energy management system as the most effective method in the improvement process. This can be achieved by adding automatic control solutions to zones (Allab et al., 2017).

Merabtine et al. argue that reducing energy consumption of buildings and improving indoor air conditions is extremely important. Within this scope, an engineering school in France was examined. Provisions were made against energy waste in the construction of this building. By 2025, significant reduction percentages in energy consumption and greenhouse gas emissions are targeted. Various designs for energy saving have been made in the facility. Despite this, a high rate of heat and electrical energy is wasted. Because the air conditioners of many places work at times when they are not used. To prevent this consumption, an energy audit was carried out for 3 years in a building. An air handling unit (AHU) is used in the facility for heating, cooling and ventilation. In winter, the air is preheated and the set temperature is adjusted to 20 ^{o}C. There are sensors in the building that control the heating and ventilation system. The ventilation flow automatically increases when the CO_2 concentration rises above 1000 ppm. In addition, by virtue of the Photovoltaic panels on the roof of the building, there is a power generation of 20 kWc. The whole building is controlled by the building management system (BMS). The BMS controls the HVAC system by collecting data such as temperature, CO_2 concentration and air flow. After 3-year research, a reduction in the costs of heating energy, which caused the highest cost, was observed. In addition, as a result of the CO_2 measurements and user surveys, indoor air quality was found to be sufficient. The model developed by the workers was confirmed by the measurement data. Thus, a fast and simple way of estimating energy consumption has been found in a place where mechanical controls are carried out not to disturb the comfort condition (Merabtine et al., 2018).

Bernardo et al. Conducted a detailed study on energy saving in one of the 6 schools studied in (Dias et al., 2016). In this context, they first identified the main causes of energy consumption. The climate conditions of the interior are examined. Based on these reviews, energy-saving measures have been designed without breaking the boundaries in indoor conditions. The building selected as a case-study is located in the central part of Portugal and has a Mediterranean temperate climate. The average temperature is 9.9 °C in winters and 20.2 °C in summers. The school has a facade in the southeast direction and one floor is approximately 10,569 m². Two classes with similar features were selected for measuring and monitoring (Area, volume, number of people, window area values). One of these two classes is in the North facade and the other is in the South facade. When the results are examined, the school's annual energy consumption is 393,609 kWh. Considering its distribution during the year, the highest energy consumption was experienced in the coldest days of winter. The reason for this situation is that the heating system operates with electrical energy. When the energy consumption of system equipment is examined, it is determined that the highest consumption is caused by lighting with 27%. In addition, it is seen that heating causes an energy consumption of 8.9%. The reason for the low energy consumption of HVAC systems is that school administrators reduce the operation of these systems in order to minimize costs. In the study, temperature and CO_2 concentration reference values were taken as 20 °C and 1250 ppm, respectively. It was observed that while the temperature was close to the reference values, the CO_2 concentration was generally above the reference value. Energy-saving suggestions have been made for each system. The lighting system is the system with the highest energy consumption, heat sensors and improvements for maximum use of daylight have been proposed for this system. When these studies are carried out, the projected energy saving is 11%. Also, considering energy consumption, relatively high values are observed outside of working hours and on weekends. For this reason, it is recommended that devices that do not have to operate continuously, such as refrigerators, should be completely turned off when not in use (computer, photocopy machine, etc.). It is emphasized that the indoor air quality decreases due to the CO_2 concentration in the classes exceeding the limit value. To prevent this situation, it is suggested to increase the working time of the ventilation system. In this case, it will have a negative contribution to energy consumption, but this is necessary for indoor air quality. To reduce consumption from the heating system, it has been proposed to reduce the reference value from 23 degrees to 20 degrees and to keep the classroom doors closed (Bernardo et al., 2017).

Ekren et al. Examined the primary school building in Izmir. The aim of the study is to create a healthier indoor environment for students. In this context, the application of heat recovery ventilation (HRV) was investigated and a pilot study was carried out. The features of the building selected within the scope of the study are as follows;

- A 3-storey building with a basement,
- It has 16 classrooms, 1 kindergarten, 350 students and 25 teachers.
- The usage intervals of the classes are 40-minute lesson periods between 8: 40-15: 20 on weekdays. There is a 10-minute break and a 1-hour lunch break.
- There are 5 factories and many small businesses near the school building.

A 30-person class on the ground floor was chosen for the study. HRV system was installed in this class. measuring devices are placed in the middle of the class. The IAQ monitoring device is placed at the students' breath level (1.1 m). The device measures the concentration of CO_2, NO_2, PM_{10}. Measurements are made at 30 second intervals. In addition, 2 different scenarios are examined, the first is that the students leave the class during the breaks as usual, the second is that the students leave the class by opening all the windows of the class.

In the study, 20-24 ^oC interval was accepted as a comfort condition and 7-point scale PMV index questionnaire was applied to students. The CO_2 concentration is modeled to determine the design flow rate of the mechanical ventilation to be used in the selected class. As a result of modeling, it was found that the flow rate should be between 3.7 L / s / p and 8 L / s / p. While designing the ventilation system, 3D modeling was done in the CFD program. Three different mechanical ventilation systems are designed. These ventilation systems are as follows:

1) Two inlets on the wall on the corridor side of the classroom and a transfer grill on the door as an outlet

2) Two air inlet grills on two cylindrical inlet ducts which are positioned along opposing upper edges of the classroom parallel to each other

3) Four inlets and five outlets.

The entrances will guide the air along the corridor, the exits aligned at the end of each column with the students. When the results are examined, it is observed that the temperature values in the school vary between 14 ^oC and 24 ^oC and the average temperature value is 17.6 ^oC. The average PMV value is -1.66. It was observed that the level of CO_2 concentration in the evening hours and on weekends when students are absent is quite low compared to weekday lesson times (3.7 and 9 times respectively). The CO_2 concentration at lunch times is almost the same as the CO_2 concentration value in the evening. Also, in the case of scenario 2, a lower CO_2 concentration was observed than scenario 1. The results showed that natural ventilation was not sufficient to keep the CO_2 concentration below 1000 ppm or 1500 ppm. As a result of CFD modeling, Design 3 was chosen as the best design. Installing the HRV unit in the classes has improved indoor air quality. While this change caused a significant decrease in CO_2 and PM concentrations, thermal comfort was not fully achieved. (Ekren et al.,2017).

The long-term monitoring and a large number of data-based studies of Almeida and Freitas are for the analysis of indoor environmental conditions. In this context, they examined 24 classroom in 9 different schools in Portugal. This review covers the winter, spring and summer seasons. Thus, they were able to evaluate for 3 different seasons during which heating, cooling or ventilation was performed. No reinforcement such as implementing HVAC system has been performed in 2 of the 9 selected schools until the date of measurement, but the other 7 have been reinforced recently. Temperature, humidity, CO_2 concentration, and ventilation rates were measured in these selected classes. These measurements continued for 3 weeks and 2 minutes intervals for each season. They used the differential equation of the mass balance of the tracer-gas (a gas that usually used for detecting gas leaks) to estimate the ventilation flow. The factors affecting the CO_2 concentration are stated as the amount that the users give to the environment, the amount expelled from the environment and the amount taken from the environment. Assumptions made within this scope are as follows; the metabolic activity of a student is 94.5W / person, the metabolic activity of a teacher is 126 W / person, and the CO_2 concentration of the outside air is 450 ppm. Firstly, one of the schools that did not strengthen was discussed, which does not have a heating system and there is only natural ventilation. In this school, the ventilation rate was found to be 0.12 1/s/person, but according to ASHRAE standards, this rate should be 5.0 1/s/person. It is seen that the other 7 schools have similar results in this field. When the results of the heating period are analyzed, the temperature is below 20 ^oC (14.9 ^oC), which is not the comfort condition. Looking at the reinforced schools, the temperature was around 20 ^oC. According to the measurement results, it can be said that all buildings comply with the reference values in terms of humidity values. This value is monitored as a minimum of 35% in all buildings. As a result of the CO_2 inspection, high levels of CO_2 concentration (more than 1000 ppm) were observed in non-reinforced buildings. The school with the best performance is below 1000 ppm in terms of CO_2 concentration. It was observed that the average temperature in the spring months was between 20-25 ^{o}C and the CO_2 level remained at an average of 1000 ppm in 5 schools. In the summer months, the temperature in all schools is above 30 ^{o}C and the CO_2 level was found at an average of 700 ppm (Almeida and Freitas, 2014).

In their research, Lei et al. Examined dormitory rooms instead of classrooms. For this reason, the values during the lesson were not taken into consideration, instead, the process of the students in the school was taken into consideration. The indoor air quality and thermal comfort of the dormitory rooms are examined in detail. There are 2 dormitory room types: 4 people and 6 people. When these rooms are examined for male and female users, a total of 4 different studies emerge. The volume of the small room is 50 m^3 and the volume of the large room is 63 m^3. CO_2 and O_2 concentration, temperature, and relative humidity are measured in each room. Measurements were made in January, between 10:00 pm-7:00 am, when the outside temperature was an average of -9 °C and the CO_2 concentration was an average of 700 ppm. The rooms are heated by finned radiators with a central hot water system. Natural ventilation is provided by opening the window manually. The window opening has 5 different levels. As the comfort conditions, the CO_2 concentration is maximum 1000 ppm and the O_2 concentration is considered to be 19.5% min. When the results are examined while the windows are fully closed, it is seen that the max and min comfort values are exceeded in all rooms. After sleep, after the 7th hour, the CO_2 level rises to 5000 ppm, which is 5 times more than the desired value. For this reason, it was determined that the window should be open during the night. The windows were then adjusted to 5 different stages, respectively, overnight. When this situation was examined, it was seen that the CO_2 concentration decreased to the desired levels while the window opening was at the highest level. However, in this version, the temperature has fallen below the desired level and comfort conditions have deteriorated. For this reason, it was deemed appropriate to open the window in the middle level. Similarly, when the opinions of the users are examined, it is seen that the PMV level does not decrease as the window opening increases. Finally, it was aimed to estimate the indoor air temperature by creating a mathematical model. The inputs of this model are O_2 and CO_2 concentration. The model was found to be consistent with the measurement results. According to the mathematical model, if the number of people in the room exceeds eight people, the area of the window opening should also be increased. Otherwise, it will not be possible to maintain comfort conditions (Lei et al., 2017).

Heebøll et al conducted a study that has similar content in many aspects with this study. The main purpose of their study is to make measurements and examine the environments where different ventilation systems are used during the heating period. The measurements that have been made are CO_2 concentration, temperature and energy consumption. Examination has conducted in a school building which is located in Denmark. Some of the classes were selected, different improvement studies were applied and the results were examined. Improvement studies that applied are as follows:

- Placing a controllable mechanical ventilation unit in Class S3.
- Automatic window opening and exhaust fan system to Class S4.
- To Class S5; automatic window opening, a system for natural ventilation and heat recovery unit on the outer wall.
- Using a screen on a wall that shows the level of CO_2 concentration in the S8 class.

The system of the Class S3 has a fresh airflow rate at the minimum when the CO_2 level is below 600 ppm. The fresh airflow rate reaches the maximum when the CO_2 level is above 800 ppm. Also, the thermostat in the classroom has been adjusted to keep the indoor air temperature at 23 ^{o}C. The automatic window opening system in classes S4 and S5 is activated when CO_2 concentration exceeds 800 ppm. The results of the measurements have examined by variance analysis. Classes S3 and S4 have less CO_2 concentration than other classes and it is below 1000 ppm. The indoor air temperature of Class S8 is quite high compared to other classes. In the classrooms where the windows do not open automatically, the window opening rate is 15% during the class usage. On the other hand, this ratio has increased to 44% in classrooms where windows are controlled automatically. Class S4, which has the lowest indoor air temperature, also has the lowest CO_2 level. As a result, the lowest CO_2 concentration was measured in the class which has a mechanical ventilation system, an automatic window opening and an exhaust fan system. When all classes are examined for indoor air temperature, it is seen that there is no significant difference between them. The temperature is usually in the range of comfort conditions (Heebøll et al., 2018).

Budaiwi and Abdou argue that by changing the operating strategies of HVAC systems in buildings, approximately 25% of energy can be saved. Within this scope, the consumption of HVAC systems for mosques has examined. Their purpose is to identify energy saving methods without disrupting users' comfort conditions. One hundred thirty two mosques that are located in the Eastern Province of Saudi Arabia is examined with separation into six groups. The most used HVAC systems are; a simple fan-coil system or the packaged system. EnergyPlus simulation program is chosen for modeling since simulation data was taken in less than 1 hour. In order to determine the accuracy of the simulation results, the real values of energy consumption and temperatures have compared with the simulation values. Very close results have been obtained in energy consumption and simulation has been proven to be correct. Although the temperature difference is slightly higher, the curves follow each other and the difference is at an acceptable level. Occupancy is an important parameter as simulation input. However, it is hard to determine the occupancy parameter since the number of people and the time spent in the mosque is changed at every prayer time. Therefore, the 1-hour occupancy rate was accepted to be 50% of the max occupancy rate. In the study, comfort temperatures were determined as 23-26 ^{o}C for summer months and 20-24 ^{o}C for winter months. When the results are examined, it is seen that in an uninsulated mosque building with a 35.5 kW cooling capacity, the comfort temperature could not be achieved. Although the mosque is used only during prayer hours, the HVAC system must work all day. To save energy most effectively, the HVAC system should be activated to start working one hour before the prayer time. By increasing the capacity of the device, it is possible to reach the desired temperature in 1 hour. In this way, since the system will operate for a much shorter time, energy-saving can be made. Another energy-saving method is to create an area divided by thin walls to the zones which have the glass and doors. Thus, insulation can be provided and comfort conditions can be approached. Finally, considering the height of the mosque ceiling, determining a lower level for blowing will reduce unnecessary use (Budaiwi & Abdou, 2013).

Theodosiou and Ordoumpozanis state that schools take first place among places where energy efficiency and air quality should be the best. In their studies, schools' energy consumption and indoor air quality were examined. For examination, schools that are located in the cold climate region of Greece were selected. First of all, architectural drawings, structural features, HVAC system features and electric bills were collected. Also, during the examination period, climate data were recorded by a meteorological station, and these data were used in the study. Users were surveyed to get information about the number and features of electrical equipment in the school, the number of teachers and students, the situations affecting energy consumption and indoor air quality. Energy consumption measurement was done manually from the meters in the power distribution unit. The temperature, humidity and wall temperature data of indoor environments were recorded for 2 months. CO_2 concentration was measured for 2 days in each school and recorded at 1 minute intervals. The results show that hydronic radiators heat only parts close to them, and comfort conditions are not maintained due to the cold air coming from outside when ventilated. No correlation was found between the properties of the buildings and heating consumption. The main factors affecting consumption like user attitude, usage of windows, setting control and maintenance of thermostats are shown as the reason for this. As a result, it has been observed that almost all school buildings do not comply with energy-saving and indoor air quality conditions. Part of the resolutions for the issue are as follows:

- Adjusting thermostats for each class separately instead of adjusting for the whole school
- Insulation and secondary glazing applications
- Increasing the sanctions by the authorities

(Theodosiou & Ordoumpozanis, 2008)

Li et al. have implemented a 3-step process to improve the indoor environment quality in meeting rooms. These stages are monitoring, diagnosis and intervention. Firstly, the temperature, humidity and CO_2 concentration of the indoor environment were measured. Secondly, an automatic control system is proposed to prevent unnecessary operation of the HVAC system. The examinations were made in an office with a subtropical climate in Hong Kong. There are 9 people working in this office and one small one big meeting room exists in there. When the collected data is analyzed, it is seen that the CO_2 level in the meeting rooms frequently rises above 1000 ppm. To reduce this intensity, a logic-based control strategy has been suggested. This control program uses real-time CO_2 concentration and temperature information. In this case, since the volume of the HVAC system will increase, energy consumption may increase. Therefore, while developing the control strategy, a balance must be struck between the efficiency of the HVAC system and the improvement of the CO_2 concentration (W. Li et al., 2018).

Walker et al. have used the Model Predictive Control (MPC), they aimed to reduce energy use in an office building in Ireland. In this optimization process, the comfort of the users was also prioritized. They concentrate on ambient temperature and CO_2 concentration. Multiple Input Multiple Output (MIMO) model was used while modeling these two variables. MPC is a model commonly used for cooling, heating and ventilation control. Modeling of the system consists of three steps: cost objective function, prediction horizon and weighting matrices. There are two different categories in MPC architecture. These categories are: centralized and distributed. Resistance-Capacitance (RC) model was used for temperature prediction. CO_2 mass balance model is used to estimate the CO_2 concentration. In the simulations, indoor air temperature is determined as 20 °C and CO_2 concentration as 800 ppm. In addition, the wind speed is considered as 5 m / s. In the simulation results, maximum error in temperature was observed as 2 °C and CO_2 concentration as ± 100 ppm. The profits in energy consumption are 30% for centralized category and 23.5% for distributed category (Walker et al., 2017).

Johnson et al. Aimed to find the optimum ventilation rate by examining the indoor air conditions in school buildings. In this context, they examined 12 different school buildings in Oklahoma City and tried to determine the indoor air quality. CO_2, CO, NO_2, temperature, and relative humidity in the classes and outside air were measured. The measurements were recorded during school hours (8:00 am to 3:00 pm). In addition, a mathematical model has been created for the ventilation rate, and the CO_2 concentration can also be estimated with this model. When the outdoor air results are analyzed, the CO_2 concentration ranged from 231 to 676 ppm. When the indoor air measurements are examined, the temperature values are generally within the range of ASHRAE standards (20-24 in winter, 23-26 °C in summer). There is an average volume of 9 m^3 per student in the classrooms. The CO_2 concentration is 90% in 3 schools and below 1000 ppm and it is 90% in the other 3 schools and below 1500 ppm. In the last school, it is over 70% 2000 ppm. Finally, the ventilation rate is modeled as an hourly change amount and this value is converted to liters/second. The estimated values match the 5 L / s ventilation rate per person determined by ASHRAE standards (Johnson et al., 2018).

Yao and Zhao conducted a study on the window opening behavior of people.

Environmental parameters of 19 dwellings in Beijing were examined. These parameters are:

- Openness of the window
- Indoor and outdoor temperature
- Humidity
- Wind velocity
- CO_2 concentration and etc.

These variables were analyzed with multivariate logistic regression models. In addition to the measurements, surveys were conducted on people living in the dwellings and occupancy rates were recorded. It has been observed that users leave their windows open longer in the summer months. However, since there is an air conditioning unit in some zones, the days when the window never opened in both summer and winter also were observed. The window opening was found to be 48% on average during the study period. It was seen that the frequency of window opening was more intense in the evening hours. The window opening rate increased when the CO_2 level in the environment increased, but on the contrary, when the CO_2 concentration reached a normal level, there was not much change in the window closing rate. As a result of the model created, it was found that the parameter that most affects the window opening is indoor and outdoor temperatures. The least influencing parameter is the wind velocity (Yao & Zhao, 2017).

Zuraimi et al. aimed to estimate the number of people in the environment by measuring the CO_2 concentration values. In this context, they recorded the number of people and CO_2 concentrations in an amphitheater with a volume of 876 m^3 for 4 months. Estimating the number of people with a concentration of CO_2 in an area with a capacity of more than 200 people is a very high number compared to the literature. To find the number of people, a single pan-tilt-zoom camera was shot at 5-minute intervals and the number of people was calculated on this image. For the CO_2 concentration, measurements were made with CO_2 sensors from 3 different regions of the hall in 5-minute intervals. The physical model of the selected amphitheater was created using the mass balance model. In addition, statistical models have been created. 3 different models created for research: Artificial Neural Networks (ANN), Prediction Error Minimization (PEM) and Support Vector Machines (SVM). Many methods such as the root mean square error (RMSE) have been used to determine the performance of these prediction models. When the results are examined, it is observed that dynamic physical models give realistic results. SVM and ANN models have performed best and the correlation coefficients are above 0.95. Although the average estimates of 200 people are made in the study, the accuracy rates are between 70-76%. This ratio shows that the performance of the estimates is sufficient (Zuraimi et al., 2017).

In the study of Kükrer and Eskin, a school building was examined in terms of thermal comfort values. Firstly, the current thermal comfort values of the building was observed, and then the development of comfort condition was examined with various designs and operational strategies. Modeling of thermal comfort is provided by Fanger model. As a model building model, a classroom building in Istanbul was selected. The heating of the building is provided by the natural gas system and the cooling is provided by the chiller unit. Temperature and humidity values were measured in the selected environments. In addition, the building is modeled in DesignBuilder software. Measurement results and model results were consistent. According to the results of the analysis, the class area located in the north were identified as the most uncomfortable location of the building in the winter months. The PMV value, which should be in the range of ± 0.5, was found to be 0.04 and -1.55. In the summer months, an increase in the temperature of the rooms on the south side was observed. Based on all this information, reducing the temperature setting to 24 ^{o}C and preheating; shading element and fresh air plant optimization; examining the effect of clothing level on total comfort scenarios were developed throughout the building. The implementation of the scenarios allowed the building to keep the average monthly PMV values in the range of -0.5 and +0.5 which is recommended by the standards.

To interpret the CO_2 concentration, Krawczyk and others have made some measurements in school buildings located in 2 different locations (Poland and Spain). Four classes were selected from each of these two school buildings and these classes are located in different floors and orientations. In addition, during the measurement process, students using each class were surveyed and their physical comfort degrees were evaluated. Temperature, pressure, CO_2 concentration and air velocity were measured in each region both in the classroom and exterior. Natural ventilation is provided in the classrooms in all examinations. A model was created to estimate the CO_2 concentration. Some of the parameters used in this model are as follows; CO_2

concentration emitted from the breath of a person, the number of people in the environment, the volume of the space, the rate of air exchange in the environment (ACH), pressure and temperature. It was monitored that the CO_2 level exceeded the limit of 1000 ppm after 35-45 minutes in all classes. This situation has been observed during long lessons with high number of students. In order to prevent this situation, ACH in classes should be between 2.5 h^{-1} and 4.5 h^{-1}. As a result of the surveys, the percentage of satisfaction decreases when the amount of CO_2 exceeds 1000 ppm (Krawczyk et al., 2016).

On the same subject, Kapalo, Domnita, and Lojkovics calculated what should be the fresh air volumetric flow rate by measuring this instead of estimating CO_2 concentration. An office on the 2nd floor of the 5-story building was chosen for the experiment. Measurements were made for 2 days during the heating period. For the exterior environment: the temperature, humidity, and CO_2 concentration are measured. For the indoor environment, the wind speed is measured in addition to the external environment parameters. Measurements were handled in 2 different time intervals, in which the CO_2 concentration increased, the user was in the office, and the CO_2 concentration decreased and there was no user in the office. The first time interval is expressed as a mathematical model of the CO_2 concentration increase. The second time interval is considered as a decrease in CO_2 concentration due to leaks from the outside air. Since the CO_2 concentration released by the breath (exhale) of a person will change according to the number of breaths per minute, it is modeled by considering different numbers. The number of breaths that produced the closest result compared to the measurement was 15.5 breaths per minute. The fresh air ventilation flow rate was calculated using the graphic method. Considering STN EN 13779, the CO_2 concentration in the office is defined to be 980 ppm by the researchers. It was found that the airflow rate should be 0.71 / h in order to achieve this limit. But in reality, this rate is 0.2 l / h. In this study, 5 different standards of Slovakia are taken into account and the air flowrate is calculated one by one. As a result, a different value is found in each calculation, and the suggestion is: "using the fresh air flow rate in an office room per person (qv = 12.5 l / s.pers)" (Kapalo et al., 2014).

In another scientific approach, Ansanay-Alex tried to estimate the number of people in the environment using CO_2 concentration. It used CO_2 levels recorded at 10-minute intervals. First, an office known to be used by one person was examined. In this office space, it has been observed how long CO_2 concentration has increased and decreased. Afterward, the situation in which there was no information about the number of rooms and people was evaluated. In order to verify this approach, tests were made by selecting a place where all physical information (such as the volume of the space, ventilation system) can be accessed. Then a mathematical model was proposed and a simulation that lasted 15 months was created with this model. The result shows that there is an acceptable error rate between the simulation result and the actual data. It is indicated that this method will give better results in spaces such as classrooms where CO_2 concentration changes will be clearer in environments with more users. However, external factors such as window openings greatly affect the result. For this reason, it is recommended that openings are taken as model inputs (Ansanay-Alex, 2014).

Çalış et al. examined a university building in Izmir. The location of the building and its purpose of use are quite similar to this study. Their aim is to examine the thermal comfort level of the classrooms in the building. June and November were selected to examine both the cooling and heating period. In these months, measurements were taken from selected classes and a questionnaire was applied to students. Indoor temperatures, relative humidity and airflow velocity were measured and recorded at 1-minute intervals. These data were used to calculate the PMV (Predictive Mean Vote) and PPD (Predicted Percentage of Dissatisfied) index values. The questionnaire was prepared according to Fanger's 7-point thermal sense scale. Thus, the participants evaluated the ambient temperature by choosing between -3 and +3. Two (D104 and D204) classes were selected on the 1st and 2nd floors, both with the same area and person capacity to conduct the examinations. Both classes have a south facade. According to the measurement results made in June, the average indoor temperature of both classes was found 28.6 ^{o}C. In November, the temperature in the classroom D104 ranges from 24.7 ^{o}C to 26 ^{o}C. In the D204 class, it is between 26.7 ^{o}C and 27.3 ^{o}C. Air flow velocity ranged from 0.01 m/s to 0.1 m/s in D104, this value was found to be a maximum of 0.04 m/s in D204. In the upstairs classroom (D204), 47% of students found the environment warm in June. This rate is higher than the classes downstairs. For both cooling and heating periods, the students evaluated the environment as slightly warm. In November, the percentage of people evaluating classes as thermally acceptable is 54% for D104 and 62% for D204 (Çalış et al., 2015).

In order to bring the CO_2 concentration to acceptable limits, Keun et al. have attempted to place a CO_2 trapping device in the air handling unit. In their study, they examined how much this device changed the CO_2 concentration and how much energy was saved in the air conditioning system. Two different tests were performed to determine the performance of the CO_2 retention device. For these tests, an office area consisting of 28 users and 800 m^3 volume was used. As a preliminary condition, one of the tests was carried out at a concentration of 360 ppm and the other at 800 ppm CO_2. As a result of the tests, they created a mathematical model to estimate the CO_2 concentration. Two different locations were chosen to calculate the energy consumption performance. These locations are Singapore on August 14 for the cooling period and Switzerland on January 30 for the heating period. Enthalpy change was used for cooling load calculation. Sensible heating was used for the heating load calculation. As a result of the calculations, it has been found that 2 kWh of energy is released per 1 kg of CO_2. When the results are examined, it is seen that there are 4 different initial ppm values. Under the condition with 1000 ppm initial value, which is the largest of these values, it is seen that after a period of non-ventilation, the CO_2 concentration rises above 2000 ppm. However, this level can be reduced up to 1200 ppm with the CO_2 holding device with 4 kg capacity. In addition, when the number of people increases in an environment with a traditional ventilation system, the CO_2 concentration rises above the limit value after a while. The time limit reached can be extended by using this device. When the modeling results are examined, it is seen that 30-60% energy will be saved in a system where this device is integrated, compared to a conventional ventilation system (Keun et al., 2015).

Rospi et al. examined 8 school buildings in the south of Italy to conduct an energy audit. The buildings are located in the region with a Mediterranean climate and seven of them do not have thermal insulation. This study was supported by the state and aimed to improve the energy performance of schools. In the study, firstly, the thermal conductivity of the exterior of the buildings was examined. In addition, the efficiency of the heating system and the energy consumption of the schools were measured. Secondly, these values were simulated in the EnergyPlus program. Finally, suggestions for energy performance are presented. The efficiency increasing methods applied to the building at the first stage are as follows:

- Thermal insulation of walls and roof
- Replacement of windows

As an alternative to these methods, replacing the old heating system with a heat pump can be offered. In addition, renewable energy solutions such as Photovoltaic panel can be added to schools.

The insulation-related improvements applied in the first stage led to a 66% reduction in energy consumption. It has been observed that an average of 48% more energy can be saved by applying other improvement suggestions (Rospi et al., 2017).

The information on which subject the studied literature is working on is given in Table 1. This table was created in parallel with the topics discussed in the study.

Table 1. Literature Subjects

Literature	CO_2 Conc.	Inside Temp.	Occup-ancy	Energy Cons.	HVAC System Operation	Window Opening
(Dias et al., 2016)	✓	✓	✓	✓	✓	✓
(Allab et al., 2017)	✓	✓	✓	✓	✓	✓
(Merabtine et al., 2018)	✓	✓	✓	✓	✓	✓
(Bernardo et al., 2017)	✓	✓	✓	✓	✓	
(Ekren et al.,2017).	✓	✓	✓		✓	✓
(Almeida and Freitas, 2014)	✓	✓	✓		✓	
(Lei et al., 2017)	✓	✓	✓			✓
(Heebøll et al., 2018)	✓	✓		✓		✓

(Budaiwi & Abdou, 2013)		✓	✓	✓	✓	
(Theodosiou & Ordoumpozanis, 2008)	✓	✓		✓	✓	
(W. Li et al., 2018)	✓	✓		✓	✓	
(Walker et al., 2017)	✓	✓		✓		
(Johnson et al., 2018)	✓		✓		✓	
(Yao & Zhao, 2017)	✓	✓				✓
(Zuraimi et al., 2017)	✓		✓			
(Kükrer & Eskin, 2017)		✓			✓	
(Krawczyk et al., 2016)	✓		✓			
(Kapalo et al., 2014)	✓	✓				
(Ansanay-Alex, 2014)	✓		✓			
(Çalış et al., 2015)		✓	✓			
(Keun et al., 2015)	✓			✓		
(Rospi et al., 2017)				✓		

After detailed literature review, it has been observed that the studies generally focused on the analysis of indoor air quality. These studies also offered suggestions to reduce energy consumption by maintaining indoor air quality. In this context, detailed analysis of the parameters that affect IAQ most like temperature and CO_2 concentration values were made by the researchers and simulations were created showing the change of these parameters over time. Occupancy and window opening inputs, which greatly affect the change of temperature and CO_2 concentration, are also the main parameters examined. With the help of collecting and analyzing all these data, suggestions to reduce energy consumption from HVAC systems are presented. Some research samples examined efficiency analyzes as case studies and showed the resulting energy savings.

CHAPTER 3
SYSTEM DESCRIPTION AND CURRENT OPERATION

In this study, 2 university buildings were compared with each other and with the classes within themselves. The aim is to make examinations and suggestions that can reduce energy consumption in university buildings without disrupting the comfort conditions. In this context, the parameters such as indoor temperature, humidity, CO_2 concentration and window opening that will affect the energy consumption and the comfort of the users have been examined. The effects of these parameters on energy consumption and indoor air quality are presented.

3.1 Characteristics of Buildings and Measured Classrooms

3.1.1. Physical Properties of Buildings

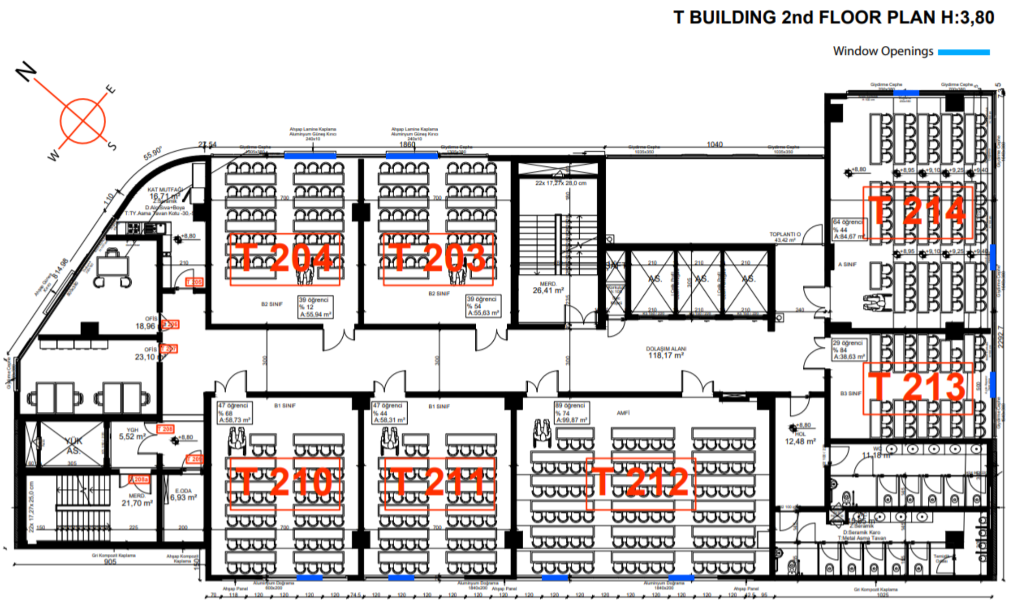
Within the scope of the study, measurements were made in classes located on different floors and directions of 2 buildings (T and Y Buildings) of Yaşar University in Bornova/ Izmir. The locations and facade visuals of the university buildings are shown in Figure 1.

Figure 1. Monitored Buildings (Y in the left, T in the right) and Their Locations

Both Y and T building have 2 basements. The number of floors of the Y building over the ground is 6 and the total usage area is 24,024 m². T building has 7 floors and total usage area is 9,056 m². There are classrooms, offices and laboratories in both buildings. The average thermal transmittance coefficients (U-value) of the buildings are 0.631 W/m²K and 0.648 W/m²K for the Y and T building, respectively (Yıldırım et al., 2019). Although the T building has a much smaller usage area compared to the Y building, the reason why U values are so close is the window-to-wall ratio on the exterior. The window-wall ratio in the T building is 0.72, while it is 0.42 in the Y building. In the selection of the classes to be measured, attention was paid to the classes on the same floors and directions in both buildings. Thus, the floor and direction relationship could be examined for two different buildings. While making the class choices in a building, different solar oriented classes were preferred and it was paid attention that these classes were at close distances. These criteria enabled a more efficient assessment by providing diversity with classrooms. (Dias et al., 2016) The area and capacity information of the selected classes are given in Table 2. The letters at the beginning of the classrooms represent the buildings where they are located, and the first number of the numbers represents the floor where they are located. The locations and directions of these classes on the floors are shown with floor plans in Figure 2.

Table 2. Area and User Capacity Information of the Classrooms

Building	**Classroom Number**	**Area [m²]**	**Capacity [student #]**
Y BLOCK	Y201	46.96	25
	Y205	26.78	25
	Y213	89.5	75
	Y214	101.8	75
T BLOCK	T(-1 B10)	97.35	89
	T203	55.63	39
	T204	55.94	39
	T210	58.73	47
	T211	58.31	47
	T212	99.87	89
	T213	38.63	29
	T214	84.67	64
	T514	99.87	89
	T516	84.67	64



a) T Building 2nd Floor Classroom Illustrations

b) Y Building 2nd Floor Classroom Illustrations

Figure 2. Location and Orientation Informations of the Zones

3.1.2. Hvac System Properties of the Buildings

In Yaşar University Y Block, as an air conditioning system, chiller is used for cooling and air handling unit and natural gas boilers for heating. In the T block, there is a VRF system which is a central system but can be used individually if desired. Capacity information of these air conditioning systems are given in Table 3.

Table 3. HVAC System Information of the Buildings

Building	Type		Capacity [kW]
Y building	Chiller		750
	Boiler		5x100
	Air Handling Unit	Cooling	440.3
		Heating	360.8
T building	VRF		590.832
	Heat recovery system		673.91

Therefore, electricity and natural gas are used as energy sources in the Y block, while only electrical energy is used in the T block. There is no mechanical ventilation system in Y block. There are ceiling diffusers in T block, one of which has a fresh air flow rate of 200-500 m^3 / h. There are 2 or 3 of these ceiling diffusers in each class. This system is central and is activated when it is opened centrally.

3.2 Measurements and Schedules

3.2.1 Measurements

Temperature, wet bulb temperature, relative humidity, CO_2 concentration, atmospheric pressure, and open or closed windows were measured for 12 months in selected classes. These measurements made in this study focused on temperature, CO_2 intensity, and window opening. All measurements were made at 15 minutes intervals throughout the day and sent to the cloud system via Wi-Fi and recorded. While measuring, 3 different devices were used (Testo, 2020). Technical specifications of these devices are given in Table 4 . The measurement type made in each class is given in Table 5.

Table 4. Technical Properties of Devices

Devices	Measurement	Measuring range	Accuracy	Resolution
160 IAQ WiFi data logger 	Humidity - Capacitive	0 to 100 %RH (non-condensing)	±2.0 %RH at +25.0 and 20 to 80 %RH	0.1 %RH
	Ambient CO_2	0 to 5000 ppm	±(50 ppm + 3 % of mv) at 25 °C	1 ppm
	Temperature	0 to +50 °C	±0.5 °C	0.1 °C
2-H1 WiFi data logger 	Humidity - Capacitive	0 to 100 %RH (non-condensing)	±2 %RH	0.1 %RH
	Temperature - NTC	$-30 to +50 °C	±0.5 °C	0.1 °C
2-T2 NTC WiFi data logger 	Temperature - NTC	-50 to +150 °C	±0.3 °C	0.1 °C

Table 5. Distribution of the Measurement Types According to Classrooms

Classroom No	Window opening	Temperature/ Humidity, etc.	CO_2 concentration
Y201	-	+	-
Y205	+	+	+
Y213	+	+	+
Y214	+	+	+
T -1B10	-	+	+
T203	-	+	-
T204	+	+	-
T210	+	+	-
T211	-	+	-
T212	+	+	+
T213	+	+	-
T214	+	+	+
T514	-	+	+
T516	-	+	-

The windows where the window opening is measured have approximately 1.30 m^2 area for the Y building and approximately 1.5 m^2 area for the T building. The windows open in top-hung outward type. The sensors are attached to both the frame and the portable part, so that the window is open when the distance between the sensors increases. When the gap between the sensors occurs, the information that the window is open is reflected to the system as "1". When the gap between the sensors decreases, the information that the window is closed is reflected to the system as "0". Thus, it can be calculated how long the window remains open by examining the hours reported as 1 in the system. The opening areas of the windows are approximately 0.15 m^2 and 0.1 m^2 for Y and T buildings, respectively. In scenarios where the window is open and closed, the positions of the sensors are shown in figure x.

Figure 3. Sensor positions for the window scenarios

3.2.2 Schedule of the Classrooms

Two education term (2018-2019 Spring semester and 2019-2020 Fall semester) in one year were examined in order to evaluate the times when the measured areas were used effectively. The dates of this semester training period and final exam period, which are examined, are given in Table 6.

Table 6. Dates of the Monitoring Periods

Fall Term Classes	February 4 – May 14, 2019	**Final Exam of Fall Term**	May 20-31, 2019
Spring Term Classes	September 16 – December 24, 2019	**Final Exam of Spring Term**	January 2-15, 2020

The course and final semester programs for both semesters are given in Appendix 1. An example program for T212, one of the most frequently used classes with the highest user capacity, is shown in The programs given under "courses" in are the curriculum of that period. The same program was applied every week during the course period in the specified class. The program under the title of final exams is valid only for the final semester and is applied within the specified 2 weeks. The grey sections show the occupancy values according to time of the lesson or exam.

Table 7. Sample Course Schedule (T212)

<table>
<tr><th colspan="6">T212 Spring Courses (04.02.19-14.05.19)</th><th></th><th colspan="11">T212 Spring Final Exams (20.05.19-31.05.19)</th></tr>
<tr><th>Hour / Day</th><th>Mon</th><th>Tues</th><th>Wed</th><th>Thurs</th><th>Fri</th><th>Mon</th><th>Tues</th><th>Wed</th><th>Thurs</th><th>Fri</th><th>Sat</th><th>Sun</th><th>Mon</th><th>Tues</th><th>Wed</th><th>Thurs</th><th>Fri</th></tr>
<tr><td>8:30-9:20</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>9:30-10:20</td><td rowspan="3">35</td><td rowspan="3">17</td><td rowspan="3">49</td><td rowspan="3">49</td><td rowspan="3">49</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">40</td><td rowspan="2">37</td><td></td><td></td><td rowspan="3">19</td></tr>
<tr><td>10:30-11:20</td><td></td><td></td><td></td><td></td><td rowspan="2">41</td><td></td><td></td><td></td><td></td></tr>
<tr><td>11:30-12:20</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><th colspan="6">T212 Fall Courses (16.09.19-24.12.19)</th><th></th><th colspan="13">T212 Fall Final Exams (2.01.20-15.01.20)</th></tr>
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</table>

3.3 Energy Consumption

Energy consumption information is not measured separately for each class. Information on the general amount of electricity consumed in the building Y can be accessed.

Energy consumption information of the Y building was available as monthly total consumption data. This total data includes the electrical energy consumed by air handling units & fan coils and chiller (chiller, tower, pumps). In addition, the amount of natural gas used as fuel was converted into electrical energy and added to the monthly total. The monthly energy consumption of the Y building in Figure 4 and the T building in Figure 5 are shown. The consumption information in these graphs is calculated only with the electrical energy values used by the HVAC system. Averages of outside temperatures within working hours for the specified month are also shown. In addition, the mode of operation of the building's HVAC system for each building is also indicated on the graph.

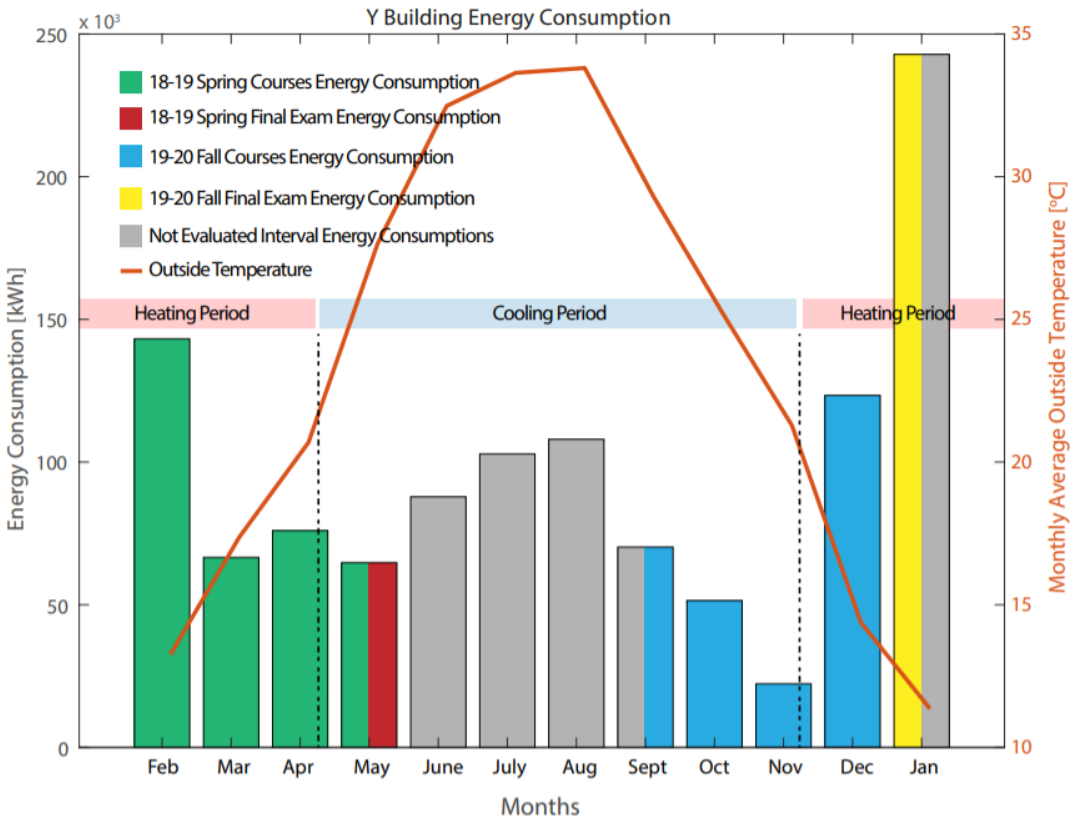

Figure 4. Monthly Energy Consumption of the Y Building

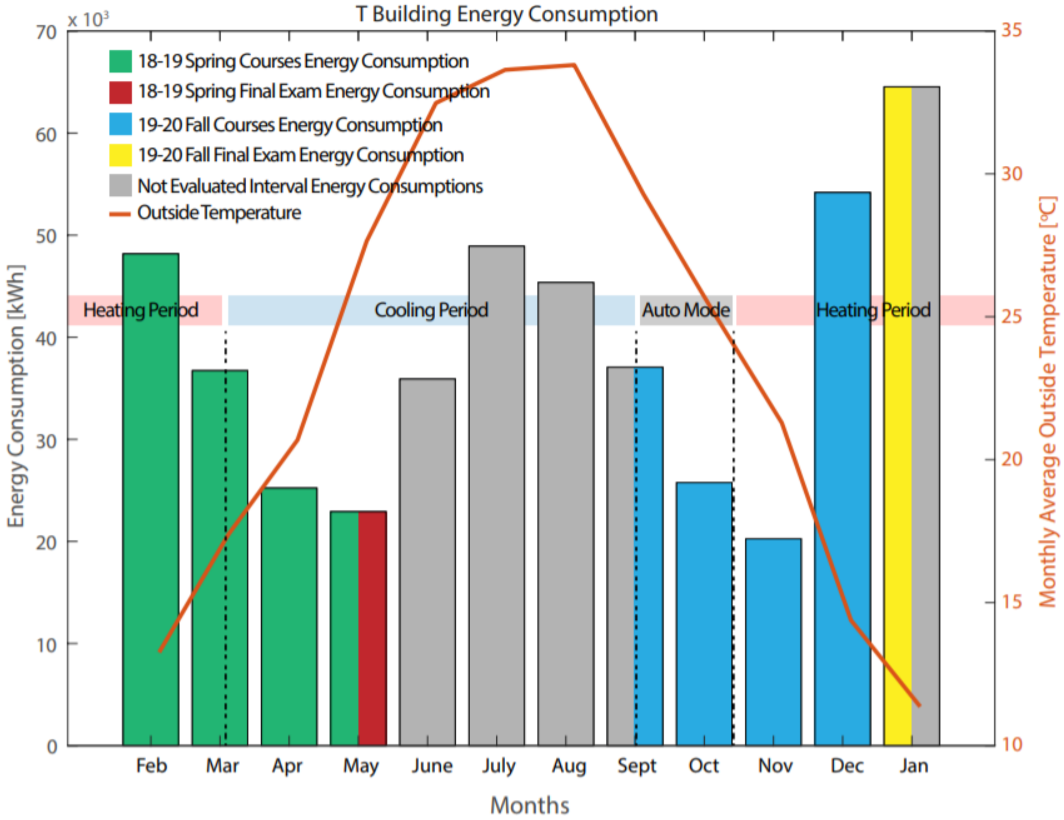

Figure 5. Monthly Energy Consumption of the T Building

Since the first months of 2018-2019 Spring semester coincides with the months of February and March, it can be read from the graph that the energy consumption is high. In these months, it can be read that the daily consumption value is generally higher than 1500 kWh. It is clearly seen that energy consumption has decreased due to not using too much HVAC system in April and May. The HVAC system has not been used very effectively since the autumn climate conditions were experienced in September, October and early November, which are the first months of the 2019-2020 Fall semester. Therefore, while the energy consumption values were stable in the first months of the graph, energy consumption increased towards the last months.

In T Building, we can access total energy consumption information on a floor basis (Electricity consumption types such as mechanical, lighting, ups are recorded for each floor). Since the VRF system is used for heating and cooling in T Building, all consumption from HVAC can be expressed as mechanical electric consumption. For this reason, building T was preferred in the energy consumption graph given in Figure 6. The values in the graph show only the mechanical consumption of the entire building, which corresponds to the HVAC system.

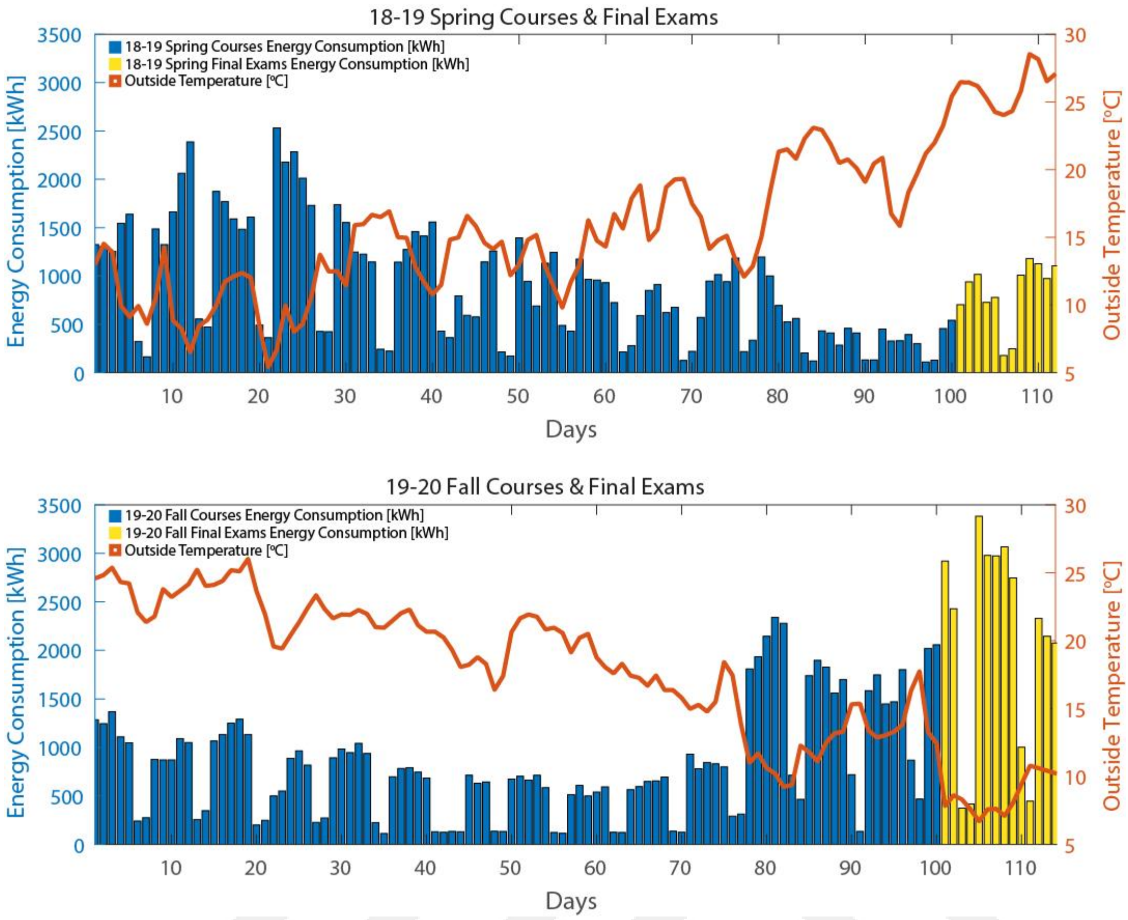

Figure 6. Daily Energy Consumption of the T Building

The HVAC system of both university buildings is operated as a central system. At certain times of the year, the technical team changes the operating conditions of the system and these changes are made throughout the building. The operating settings of the system are determined by the outside temperature or the returns from the users. There are 3 operating modes in HVAC operating settings. These are heating, cooling, and Auto mode. In heating mode, the system only blows hot air and a temperature range that users can set for the blowing temperature is entered into the system. Cooling mode works in the opposite way of heating mode. In Auto mode, cooling and heating modes are combined. Users can choose the system settings they want from the climate control in the classrooms. The air conditioning system blows hot or cold air according to the user's choice. In addition, the opening and closing hours of the air conditioner are registered into the system in auto mode, the system starts to operate automatically at these hours. Operation charts are given periodically for all modes in Table 8 and Table 9, respectively. In these tables, the operating mode information of the system and the allowable control set temperature range in that mode are given.

Table 8. Operation Table of the HVAC System (18-19 Spring) of the T building

Changing date	Working mode	Control set temperature [ºC]	Explanation
04.02.2019	Heating	23-25	The system starts automatically at 7:30 in the morning and closes at 17:30.
18.03.2019	Heating	23-25	The automatic start of the system has been closed. It is controlled manually.
25.04.2019	Cooling	23-25	The system is set to cooling mode. Automatic operation is not activated. It is controlled manually.
21.05.2019	Cooling	23-25	The system starts automatically at 7:30 in the morning and closes at 17:30.

When the operating schedule of the HVAC system for the 18-19 spring semester is examined;

- With the start of the 18-19 spring lesson period, the system is set to start automatically at 7:30 in the morning. It closes automatically at 17:30 in the evening. (Automatic operation setting is valid for weekdays.)
- On 18.03.19 the system's automatic start command was closed. If necessary, the system is manually controlled and the temperature set value has not been changed. This date coincides with the 43rd day of the semester. Due to the increase in the outside temperature and the automatic opening of the system is closed, users have reduced the usage times of the system. This situation caused a general decrease in energy consumption starting from the 43rd day. This drop in energy consumption can be seen from the graphic in Figure 6.

- The VRF system was put into cooling mode on 25.04.19 with the mean air temperature rising above 20 °C (this date corresponds to the 81st Day of the period). However, the automatic activation system is closed. The decrease in energy consumption from this day on can be interpreted as the users' temperature comfort values are sufficient and they do not use the air conditioning system.
- The system is set to run automatic cooling mode at 7:30 on 21.05.19. This date coincides with the 2nd day of the exam period. The decrease in energy consumption until the 81st day has ended and consumption has started to rise again. The automatic operation setting may be shown as the reason for this situation.
- During the 2 weeks of the final exams, energy consumption is higher compared to the previous 2 weeks. The reason for this situation is that both air conditioners are operated more due to higher participation in the final period and increased outdoor temperature.

The operating schedule of the HVAC system for the 19-20 fall semester is given in Table 9.

Table 9. Operation Table of the HVAC System (19-20 Fall) of the T building

Changing date	Working mode	Control set temperature [°C]	Explanation
16.09.2019	Auto	20-23	The system starts automatically at 8:00 in the morning and closes at 17:30. Auto mode, heat 20 and cool 23 set value adjusted.
25.10.2019	Cooling	20-23	The automatic start of the system has been closed. It is controlled manually.
30.10.2019	Heating	24-27	The system starts automatically at 8:00 in the morning and closes at 17:30.

When the operating schedule of the HVAC system for the 19-20 fall semester is examined;

- With the start of the lesson period, the system was set in auto mode to start working automatically at 8:00 in the morning. In this mode, users can use the system in heating or cooling mode. However, as the outdoor temperature is around 20-25 °C, the users usually shut down the system. This ensured that the energy consumption did not increase excessively during the period until the air temperature would decrease.
- Due to the republic holiday, the automatic operation setting of the system was closed between 25.102019-30.10.2019. These dates are between the 41st and 44th of the semester. The graph also shows that energy consumption is at a minimum level these days.
- With the decrease in air temperatures on 30.10.2019, the system started to be used in heating mode. However, since the average temperature value felt during the day did not fall to very low levels, users did not prefer the air conditioning system effectively.
- Since the 75th day of the semester, the air temperature has dropped below 15 °C, there has been a serious increase in energy consumption.
- Outside temperature was below 10 °C in the final period. Therefore, there has been a 2-fold increase in energy consumption.

CHAPTER 4
METHODOLOGY

4.1 Comfort Conditions

In this study, while evaluating the effect of indoor air quality on comfort conditions, CO_2 concentration and temperature parameters were focused. It was accepted that the indoor air temperature should be higher than 20 °C in order to provide comfort conditions (Lei et al., 2017; Keun et al., 2015). This condition is in the range of 20-24 °C in some studies (Bernardo et al., 2017; Johnson et al., 2018). According to EN152151, heating operative temperature should be 20 °C and cooling operative temperature should be 26 °C (Olesen, 2007). Figure 7 shows ASHRAE thermal comfort zones. The range of 20 °C to 27 °C is expressed as still air comfort zones (ASHRAE, 2004).

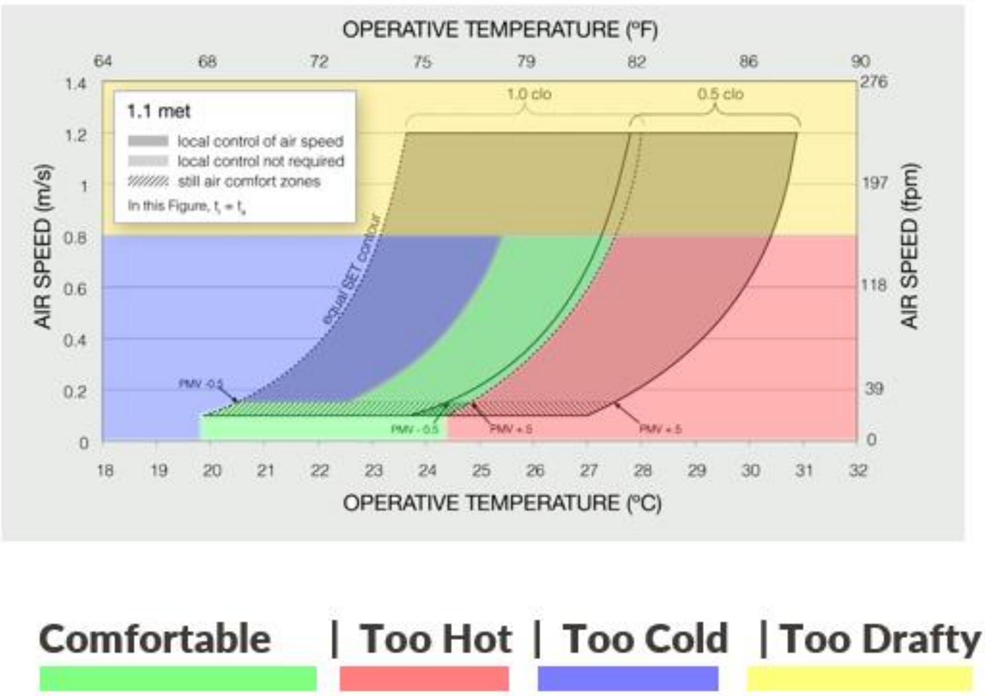

Figure 7. Comfort Conditions Range for ASHRAE (SimScale, 2019)

In many studies in the literature, it has been emphasized that the most suitable CO_2 concentration for human health effects should be less than 1000 ppm (Krawczyk et al., 2016; Kapalo et al., 2014; Walker et al., 2017; Heebøll et al., 2018). Likewise, it is stated that the CO_2 level for lecture classrooms in ASHRAE standards may be 539 ppm (970 mg / m^3) more than the CO_2 concentration value outside (Persily, 2017). The CO_2 concentration in the outside air is considered to be in the range of 400-450 ppm. (Krawczyk et al., 2016; Almeida and Freitas, 2014). In this case, the acceptable amount of CO_2 concentration in the classes is approximately 1000 ppm. In some studies, it has been said that it is an acceptable level to increase this value up to 1500 ppm (Dias et al., 2016; Almeida and Freitas, 2014; Bernardo et al., 2017; Johnson et al., 2018)

4.1.1. Survey Study and PMV Calculation

The degree of thermal comfort significantly affects the work efficiency and productivity of students and teachers. The main parameters affecting thermal comfort are personal and environmental factors. The main personal features for investigations are weight, height, age, gender and activity level (met). Environmental parameters include air temperature, average radiation temperature, air flow rate, and relative humidity (Ekren et al., 2017). As an indicator of thermal comfort, estimated average voting PMV value is used according to ISO 7730 (ISO7730, 2005) and ASHRAE (The American Society of Heating, Refrigerating and Air-Conditioning Engineers) (ASHRAE, 2010) standards. A questionnaire was applied to the students to determine this value. The questionnaire was prepared according to Fanger's (Fanger, 2002) 7-point thermal sense scale. In order to find out the PMV value, a survey including questions such as gender, height, weight and the level of temperature felt by the users were prepared. This scale is given in Table 10 and the survey questions applied are given in Appendix 2.

Table 10. Scale of the PMV Index

Cold	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot
-3	-2	-1	0	1	2	3

Since all of the students participating in the questionnaire are not at the same level of satisfaction, the average of classrooms' PMV value is taken into account when conducting evaluations. Thermal comfort level categories were used to evaluate this average value. These categories are given in Table 11.

Table 11. PMV Categories

Category	PMV
A	-0.2<PMV<0.2
B	-0.5<PMV<0.5
C	-0.7<PMV<0.7

Category A represents the highest level in terms of thermal comfort. This category is recommended for people with disabilities, sick people, elderly people and children who require special care. The PMV value is expected to be in the range of -0.2 to +0.2. For category B, the PMV value is desired to be between -0.5 and +0.5. Category B represents the normal level of expectation for new and renovated buildings. Category C is expressed as a moderate expectation and is used for existing buildings. (ASHRAE, 2010)

In this study, the CO_2 concentration limit for air quality under healthy conditions is set to 1000 ppm. The indoor air temperature was chosen as 20 °C for the heating period and 24 °C for the cooling period. The PMV values determined according to the survey results are presented in Section 5.4.

4.2 Data Analysis

The data collected during the 2 academic semesters were analyzed in 4 groups (as 2 academic semesters and 2 final exams) stated in Table 6. It was stated that temperature, humidity, CO_2, and window opening were measured in the classrooms. In other words, the occupancy value is not measured with the help of a sensor. However, it is possible to reach the number of people enrolled in the course and the number of people in the final exams. For this reason, in the analyses where occupancy is important, the final period will give more realistic results. The reason for this is that the participation in the final exam is at the maximum level. In the course period, the amount of participation varies from course to course, but it is estimated to be between 40-70%.

Measurement data were analyzed in 2 different cases. These cases contain data in the final and course periods of the classes and are as follows:

1. *The relationship between CO_2, occupancy and window opening:*

2. *The relationship between temperature, occupancy and window opening.*

In addition, the relationship between the energy consumption of the T building and the temperature is examined under the topic Energy consumption analysis. The reason why T building is preferred at this stage is that the building's HVAC system is VRF, and the analyzers in the building can only access the electricity consumption data from the mechanical system.

4.2.1. General Measurement Data Analysis

In this section, there is a general analysis of the measurements made during the spring and fall semesters. All of the measured data is provided at 7/24 and 15 minutes intervals and sent to the cloud system every 12 hours. All of the graphics from Figure 8 to Figure 15 were obtained from this cloud system. First of all, general graphs of CO_2 concentration and indoor temperature are given for both periods. Graphics are raw data. For this reason, working hours and weekends are not separated. The graphics cover the time from the first day of the semester until the last day of the final exams.

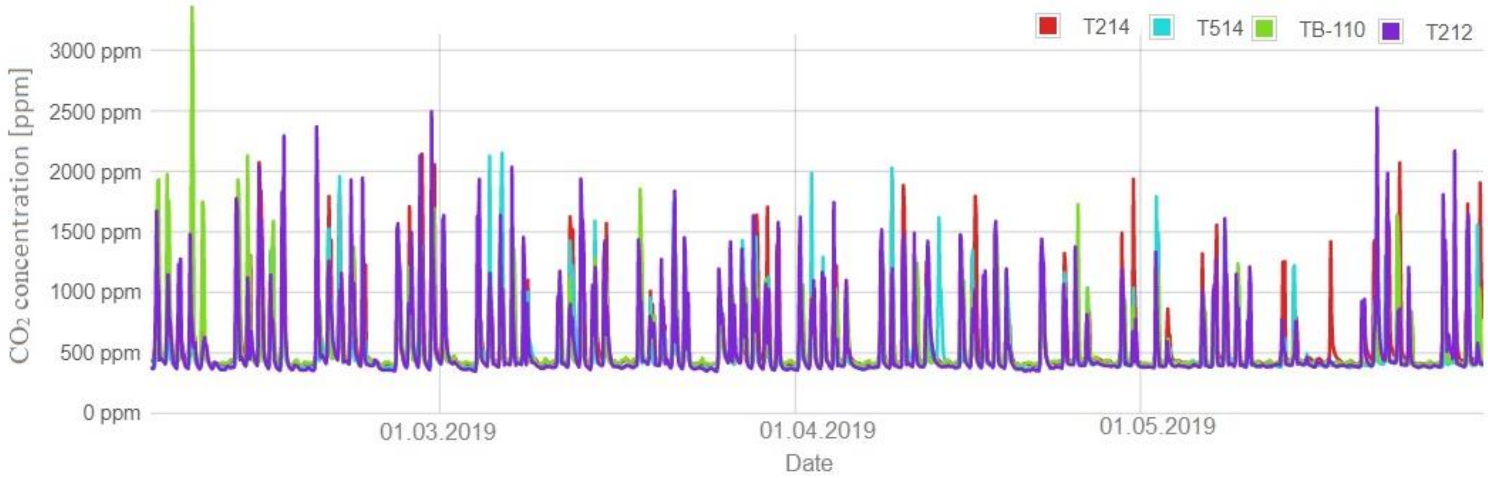

Figure 8. Spring Term CO_2 Concentration Data for T Building Classes

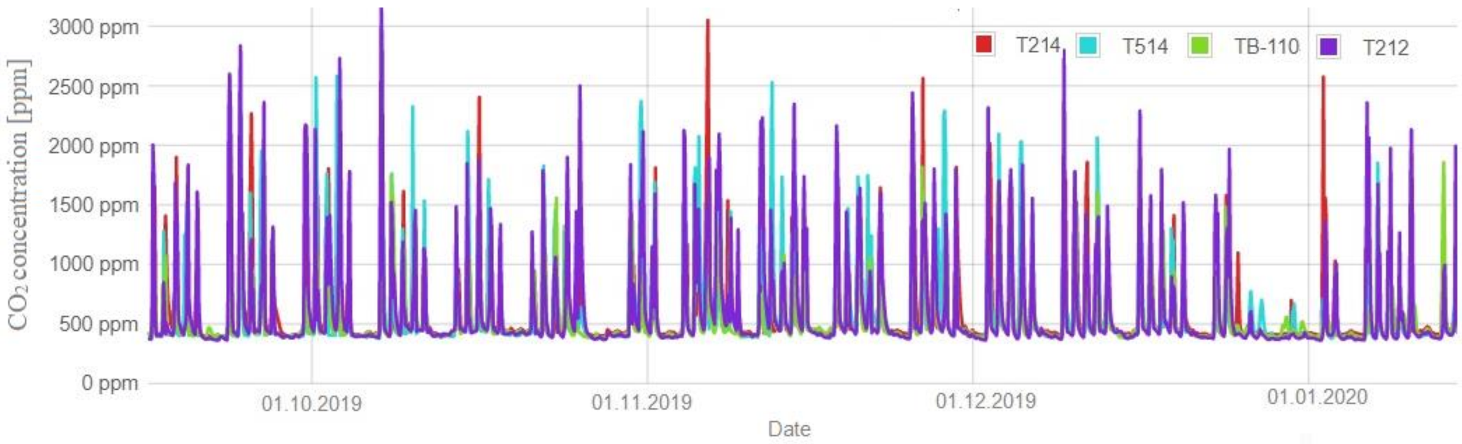

Figure 9. Fall Term CO_2 Concentration Data for T Building Classes

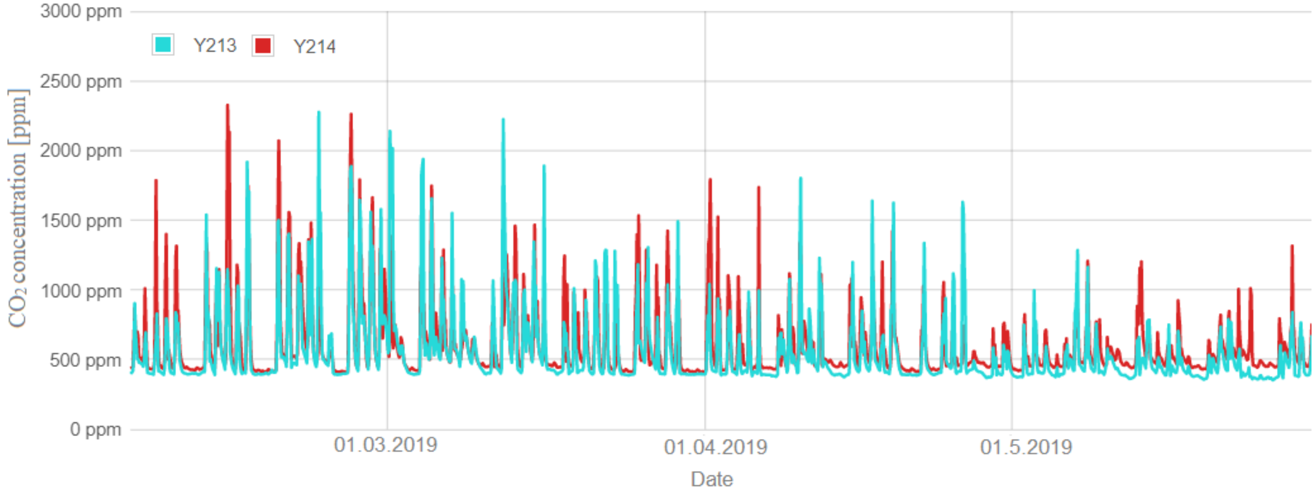

Figure 10. Spring Term CO_2 Concentration Data for Y Building Classes

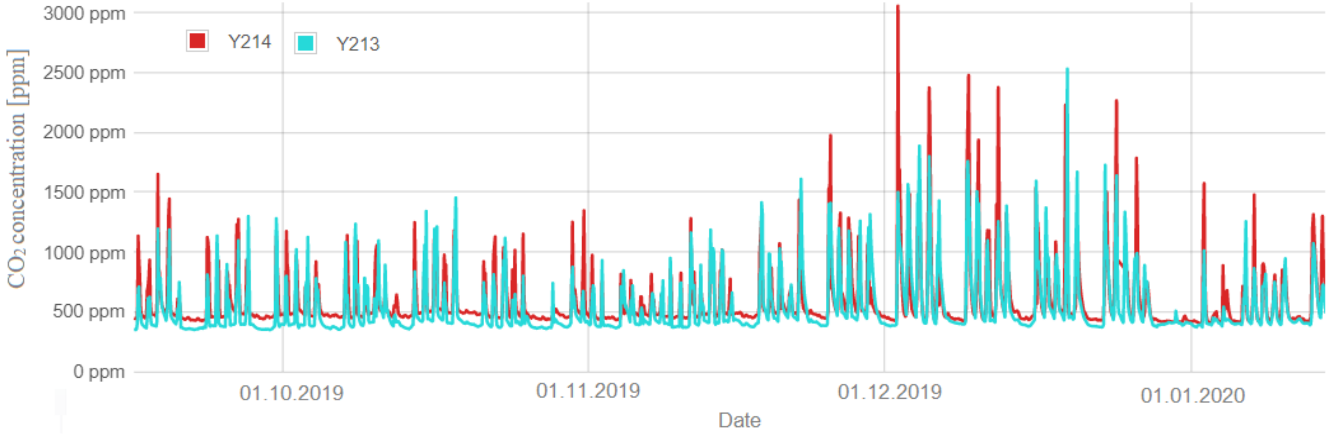

Figure 11. Fall Term CO_2 Concentration Data for Y Building Classes

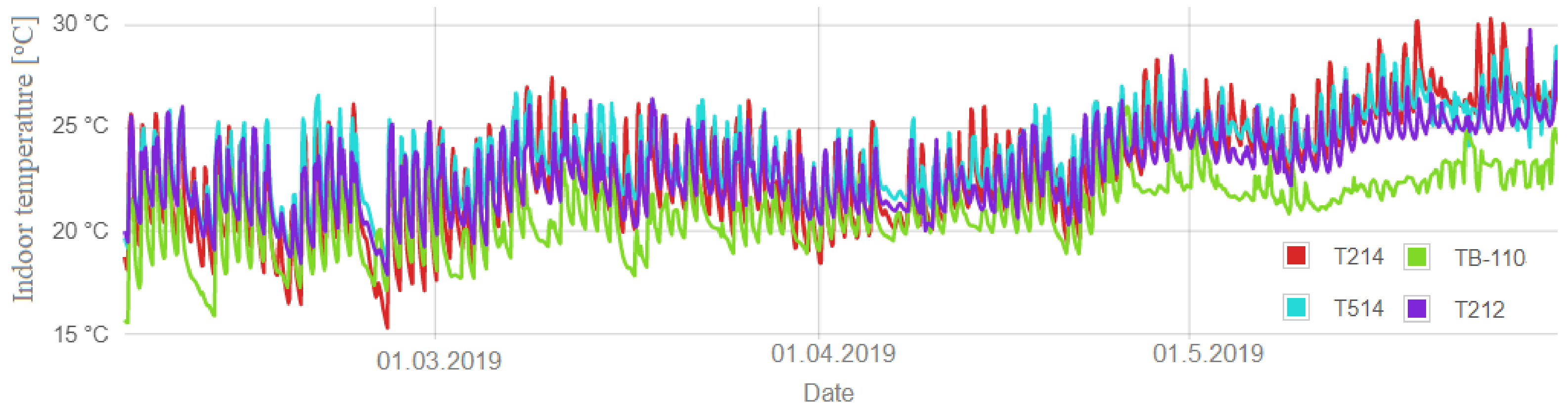

Figure 12. Spring Term Indoor Air Temperature Data for T Building Classes

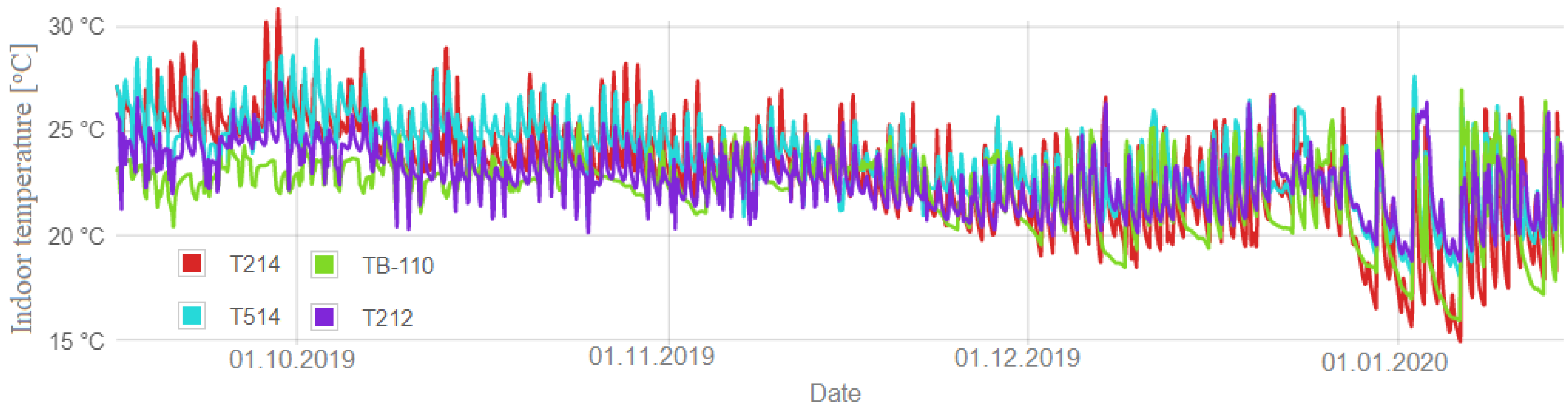

Figure 13. Fall Term Indoor Air Temperature Data for T Building Classes

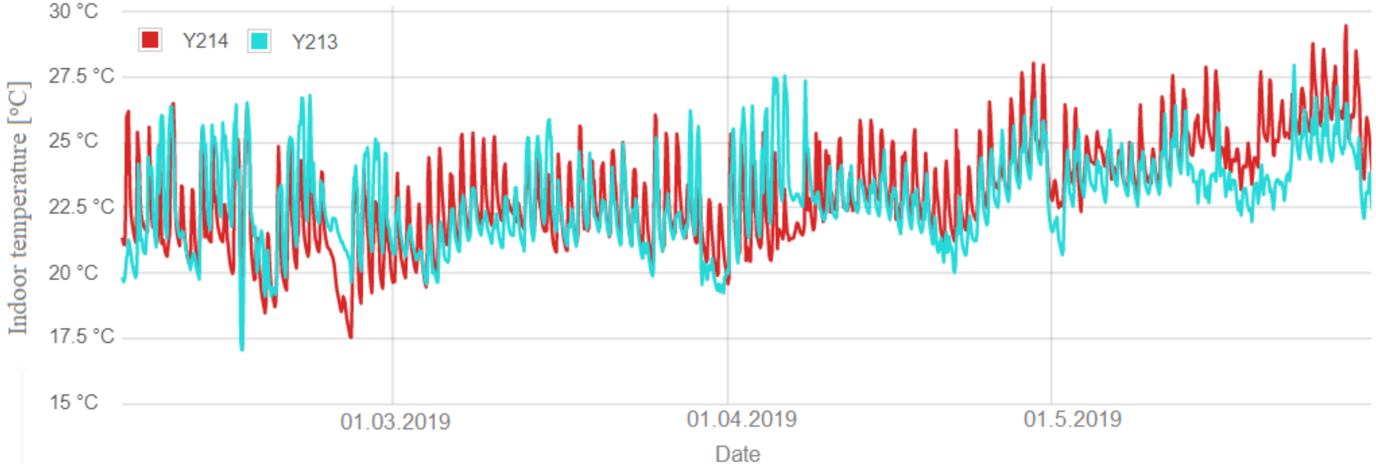

Figure 14. Spring Term Indoor Air Temperature Data for Y Building Classes

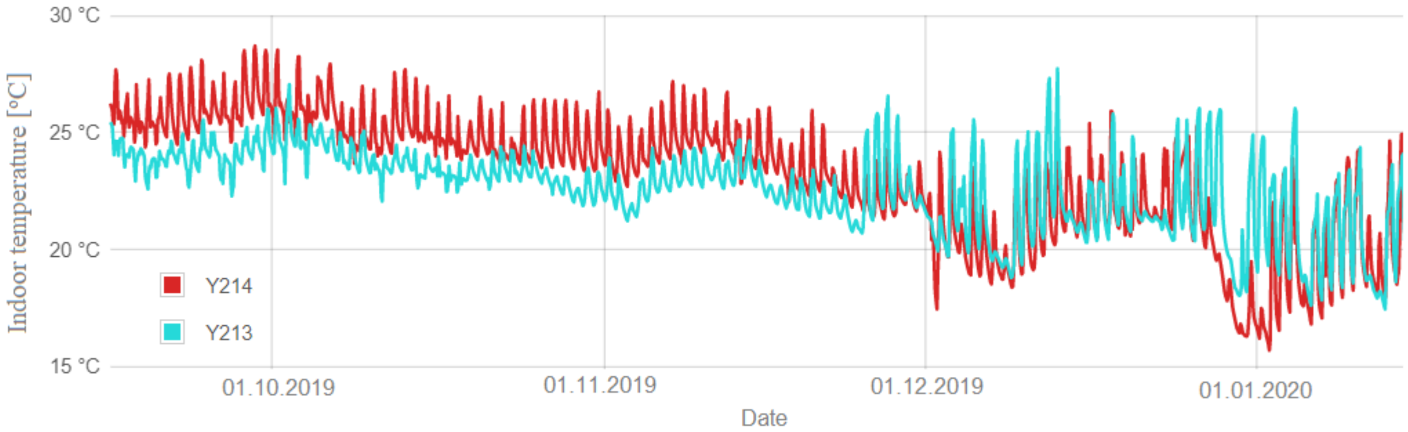

Figure 15. Fall Term Indoor Air Temperature Data for Y Building Classes

At this stage, mean, max, min, and standard deviation values of the measured parameters for all monitoring times are given. Thus, general information about the periods followed can be obtained. Table 12 contains the values of outdoor air, indoor air, and energy consumption. Considering the spring and fall course periods, it can be seen that the average outdoor temperatures are close to each other since it is a 4-month period. However, when the final periods are considered, it is observed that there is a temperature difference of approximately 20 °C between the average outdoor temperatures. The reason for this may be that the final periods are a short period of 2 weeks and coincides exactly with the summer/winter months.

Table 12. Energy Consumption, Inside&Outside Temperature Values for Classes

	Spring Courses (04.02.19-14.05.19)				Spring Final Exams (20.05.19-31.05.19)			
	Mean	Max	Min	StDev	Mean	Max	Min	StDev
Outside Temp. [°C]	17.15	31.5	3.76	5.38	29.52	35.9	21.9	2.32
Inside Temp. [°C]	23.79	28.8	18.23	1.41	25.5	28.98	23.55	1.13
Energy Cons. [kWh]	884.07	2530.53	109.08	603.48	831.53	1179.03	176.76	323.80

	Fall Courses (16.09.19-24.12.19)				Fall Final Exams (02.01.20-15.01.20)			
	Mean	Max	Min	StDev	Mean	Max	Min	StDev
Outside Temp. [°C]	20.99	31.4	7	5.40	9.67	14.2	5	2.19
Inside Temp. [°C]	23.89	28.58	19.21	1.5	22.48	28.59	16.71	2.44
Energy Cons. [kWh]	836.02	2339.44	112.96	558.81	2092.02	3381.87	373.06	1039.34

While determining the values in Table 12, outdoor and indoor temperatures were calculated using the values measured in the working hours (8:30-18:30) and weekdays. Temperature measurements were made in 15-minute periods. Energy consumption is the value of 15-minute periods for the whole day. Considering the course periods in Table 12, the sum of average indoor air temperature and the standard deviation value is 25.20 ºC for the spring semester and 25.39 ºC for the fall semester. In this case, it can be said that the indoor air temperature is at a high level during the lesson times. During the spring period, the heating system worked between 4 February and 25 April, but in the middle of this process (18 March 2019), the automatic activation of the system was turned off and the users started the heating system when they deemed necessary. As seen in Figure 6, the increase in outdoor temperatures that started after March 18 caused users to run the system less. The cooling system, which was put into operation as of April 25, worked until May 31. In other words, comfort conditions can be considered close to 24°C, which is considered suitable for the summer period. Thus, the mean plus standard deviation value is 1.20 °C degrees above the comfort condition and is at an acceptable level. However, in the fall period, 1.5 months of auto mode (16 September-30 October) and 2.5 months of heating mode (30 October-15 January) are active. Looking at this period, the mean plus standard deviation value is 5.38 °C degrees above the 20 °C comfort condition accepted for the winter months. Therefore, it can be predicted that a set value higher than required for heating mode is determined. The standard deviation of the temperature values and the sum of the average temperature value were found 26.63 °C in the spring final period and 24.92 °C in the fall final period. It is expected that the temperature will be high for the spring final period that coincides with May. In general, when the values were examined, it was seen that the indoor air temperature was above the standard.

4.3 CO_2 Concentration Calculation

CO_2 concentration value was measured in the classrooms. The CO_2 concentration in these measurements was supported by a mathematical model. This calculation was developed by the mass balance equation of CO_2 gas. Firstly, the mass balance equation of a ventilated area is as follows (Almeida and Freitas, 2014);

$$V\frac{dC(t)}{dt} = G + Q.C_{ex} - Q.C(t) \qquad \text{Eq. 1}$$

Where, V is the volume of a zone, C(t) is concentration of CO_2 at t, G is generation rate of carbon dioxide, Q is volume flow rate into a zone and C_{ex} is the outdoor carbon dioxide concentration. Equation 2 is the result of the analytical solution achieved by integrating equation 1.

$$C(t) = C_{ex} + \frac{G}{Q} + \left(C_0 - C_{ex} - \frac{G}{Q}\right) e^{-\left(\frac{Q}{V}\right)t} \qquad \text{Eq. 2}$$

Where C_0 is initial carbon dioxide concentration in zone. The formula that is based on calculation is Eq.2. The values obtained as a result of this formula are calculated using MATLAB software. By establishing a loop in MATLAB, CO_2 concentration change was found in the desired time interval.

If there is no user to emit CO_2 in the environment during a test, the CO_2 concentration in the indoor and outdoor environment is expected to be close to each other. Thus, when the CO_2 production rate and the amount of outdoor CO_2 concentration are ignored, the equation can be simplified as follows:

$$\frac{Q}{V} = n = \frac{\ln\left(\frac{C_0}{C(t)}\right)}{t} \qquad \text{Eq. 3}$$

Where n is the air change rate (ACH). In Eq.3, the equation required to calculate the amount of ventilation in an environment is given. In the calculation, the change of CO_2 concentration in the first condition over time is recorded and the slope of the linear graph of the change gives the number 'n'.

CHAPTER 5
RESULTS AND DISCUSSION

Within the scope of the study, measurements were made for 12 months in 14 classes in 2 university buildings. The combinations of temperature, relative humidity, CO_2 concentration, pressure, and window opening parameters were measured according to the class properties. Measurement results made with devices fixed on the class walls were sent to the cloud system via Wi-Fi and stored there. This study focuses on examining the parameters of temperature, CO_2 concentration, and window opening. There are a total of 6 classes (2 in the Y building and 4 in the T building) where it can be reached to all of the environment parameters and the number of people in the classes. For this reason, the data presented throughout the study were examined in these 6 classes.

In this chapter, the measurement data collected are analyzed. While conducting analysis, first of all, the effects between CO_2 concentration, occupancy and window opening parameters were examined. Then, the effects of temperature, occupancy and window opening were examined. Secondly, the effect of the energy consumption data given in section 3.4 and the HVAC system operating modes are analyzed in more detail. Finally, a detailed review was made on the CO_2 concentration parameter. The average CO_2 concentration data in the classes were evaluated according to the comfort conditions. With the loop created by using MATLAB software, the CO_2 concentration changes in the classes are modeled.

5.1. Measurement Data

In this section, the measurement values of the classes examined are presented with graphics. The examinations were first made on a class basis. In the examinations made in the classrooms, the focus was on the values of CO_2 concentration, temperature, window opening, and occupancy. In this section, the measurement results of the classes selected as an example among the measured classes are evaluated. Approximately the same results and the same interpretations were achieved in all classes. Graphics are examined in each class and given in Appendix 3.

5.1.1. The Relationship between Carbon Dioxide (CO_2), Occupancy and Window Opening

While creating the graphics in this section, since the number of occupancy is known, it was primarily examined with the data of the final period. Only measurement data of the exam days were used.

Firstly, the comparison of the user amount of the Y214 class with the CO_2 concentration for the fall final period is given in Figure 16. In general, it appears that when the density of people increases, the concentration of CO_2 increases and even reaches the limit levels.

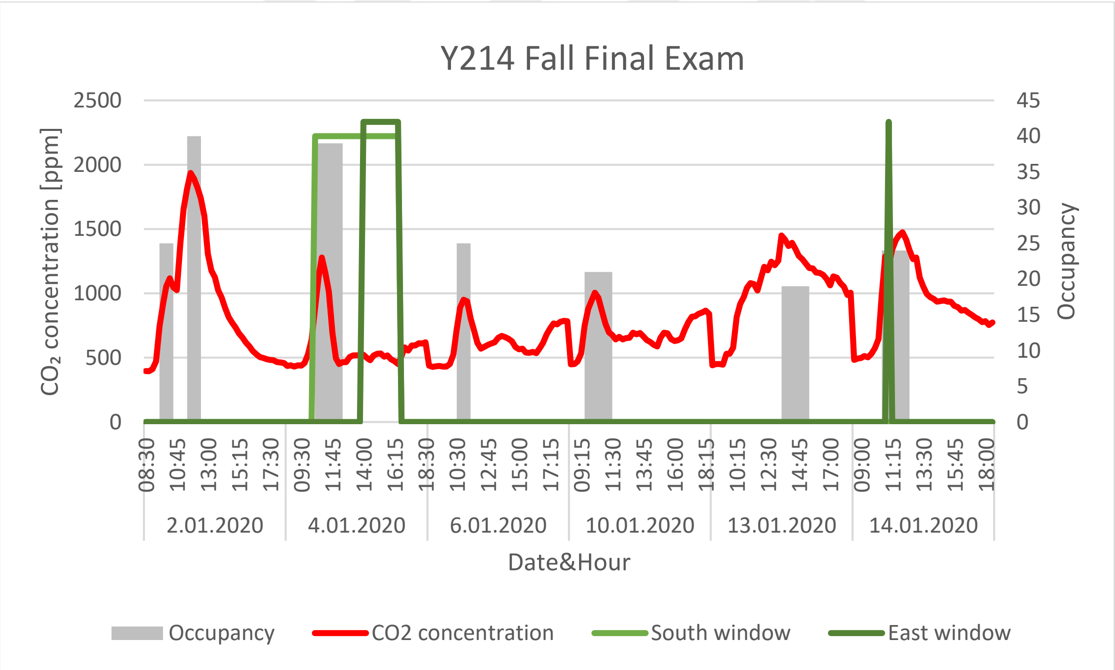

Figure 16. CO_2 Concentration and Classroom Occupancy in Y214 for Fall Final Exam Period

In Figure 16, looking at the situation in which the exam is held in the classroom, it is clearly seen that the concentration of CO_2 increases rapidly when there are students in the classroom. Since the examined dates are in January, the outside temperature is low and the windows are not opened very often. It seems that only one of the 5 exam days opened the windows. On the other days, the decrease in CO_2 intensity coincided with the middle of the occupancy block, and after a class evacuation, it proceeded with a slow slope. This is due to the fact that there are more students in the classroom in the first minutes of the exams. It can be observed that the ppm level decreases with the decrease in the number of students in the following minutes. However, when the days with window openings are examined, it is seen that there is a rapid decrease in CO_2 concentration by opening the window. For example, on 13.01.2020, it took approximately 3 hours for the CO_2 concentration, which increased to 1500 ppm during the exam, to fall back to 500 ppm. However, approximately 30 minutes was enough for the value, which reached 1300 ppm on 4.01.2020 with the windows open, to decrease to 500 ppm. As another example, although the CO_2 level is 2300 ppm in an exam for 40 people on 2 January, the level of CO_2 is seen as 1300 ppm in an exam for 40 people on 4 January. The reason for the decrease of approximately 1000 ppm can be interpreted as the window is open in the exam held on January 4.

Secondly, the graph created with the measurement data of Y214 class for the Spring final period is given in Figure 17. Unlike the fall period, in this part, since the final period coincides with May, the outside temperatures are high and the window opening rate has increased considerably compared to the final period in January.

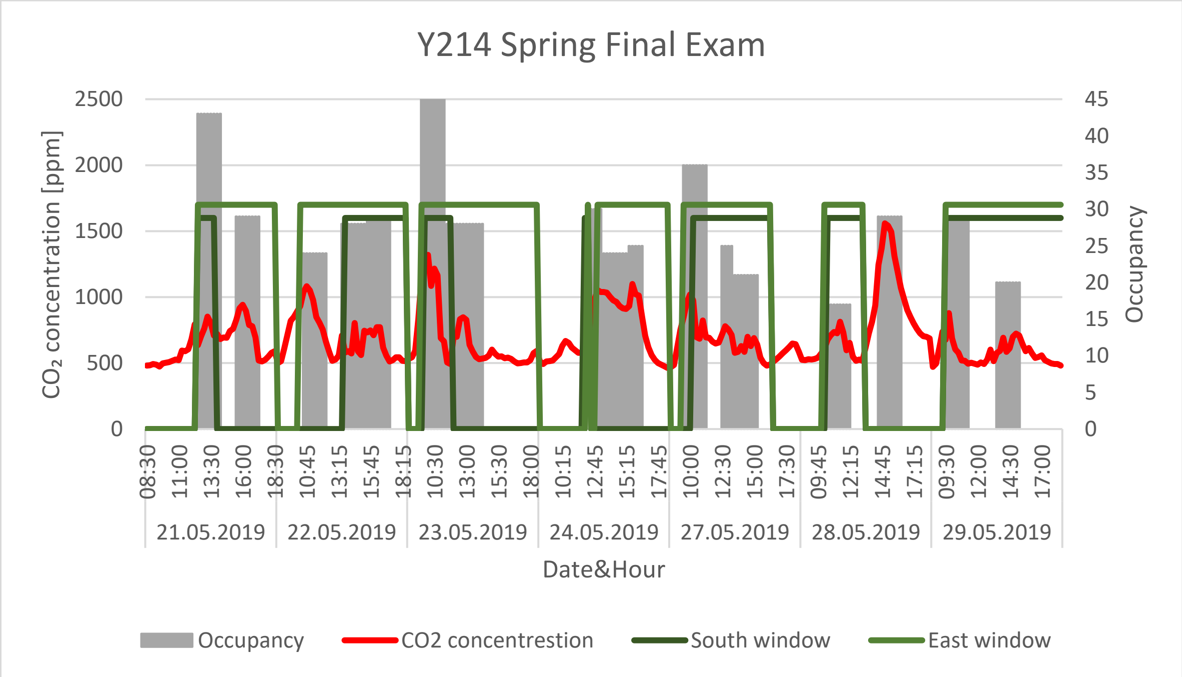

Figure 17. CO_2 Concentration and Classroom Occupancy in Y214 for Spring Final Exam

When Figure 17 is examined, it is observed that only 1 of the 16 exams held in total did not open any windows. Thus, only one exam showed a high drop in CO_2 concentration compared to the fall period when the window was opened. During the fall, the CO_2 concentration reached a maximum level of 1800 ppm. While the CO_2 average for the same period is about 1000 ppm, the max value rises to 1500 ppm in the spring period and the average is in the range of about 700 ppm. Thus, it can be said that the window opening is the most effective parameter to decrease the ppm level.

In order to explain this situation more clearly, 3 exams with the same number of people but with a different number of windows are shown in Figure 18.

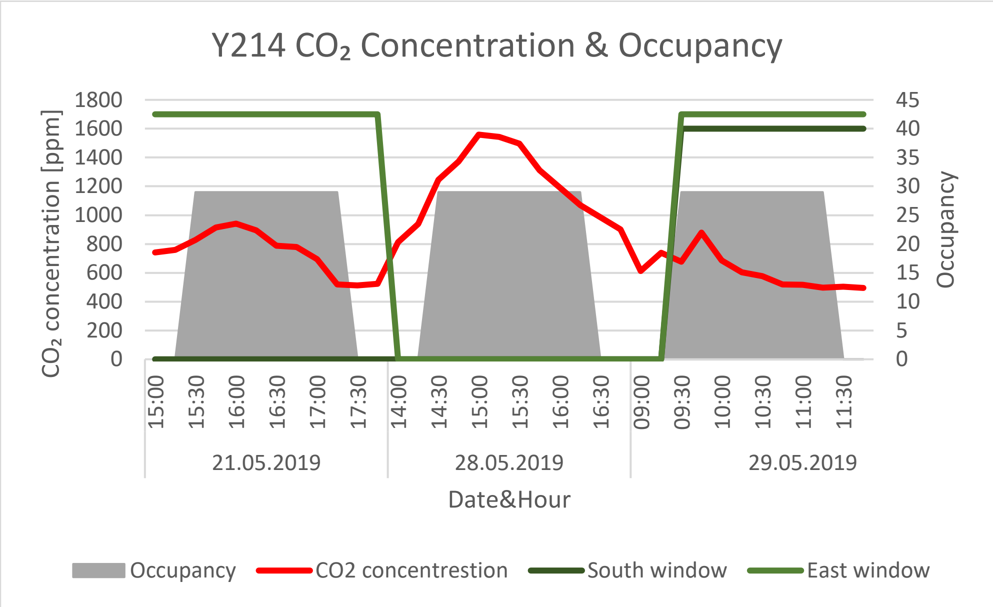

Figure 18. CO_2 Concentration and Classroom Occupancy in Y214 for 3 Exams

An equal number of participants (29 people) participated in these 3 exams. The exams were named as the 1st, 2nd and 3rd exam in the order in the chart and CO_2 concentration examinations are given in Table 13.

Table 13. CO_2 Concentration Variation Analysis for Three Exams

Exam	Window opening	Ave. CO_2 conc. [ppm]	Max. CO_2 conc. [ppm]	Min. CO_2 conc. [ppm]	Difference btw max & min [ppm]
1	1 win.	795.12	941	520	421
2	no win.	1348.25	1559	1070	489
3	2 win.	619.5	878	496	382

In the exams in the table, occupancy values, which are one of the most important parameters affecting CO_2 concentration outside the window opening, are the same.

When the values are examined, it can be clearly said that the window opening significantly affects the CO_2 concentration. The CO_2 concentration in the classroom has decreased by 41% when a single window is open compared to when no window is open. When 2 windows are opened, there is a 54% decrease compared to when no window is open. These rates are calculated based on the average CO_2 concentration. Comparing the situations with 1 and 2 windows open, a 22% reduction in CO_2 concentration was observed when 2 windows were open. According to these results, when the supply of fresh air to the environment was provided, increasing the amount of incoming air did not cause a great change. However, it can be said that the CO_2 concentration decreases at a higher rate when there is air inlet from the ventilation to a completely isolated environment.

Since the lecture period is a 14-week period, 1 week was selected and investigations were carried out. Midterm exams are held at 6-7-8 weeks and are usually concentrated at Week 7. Therefore, the 6th week, just before midterms, was chosen as the week to be examined. Figure 19 is created with the information of the 6th week for the fall semester. First, the concentration of CO_2 and occupancy were compared.

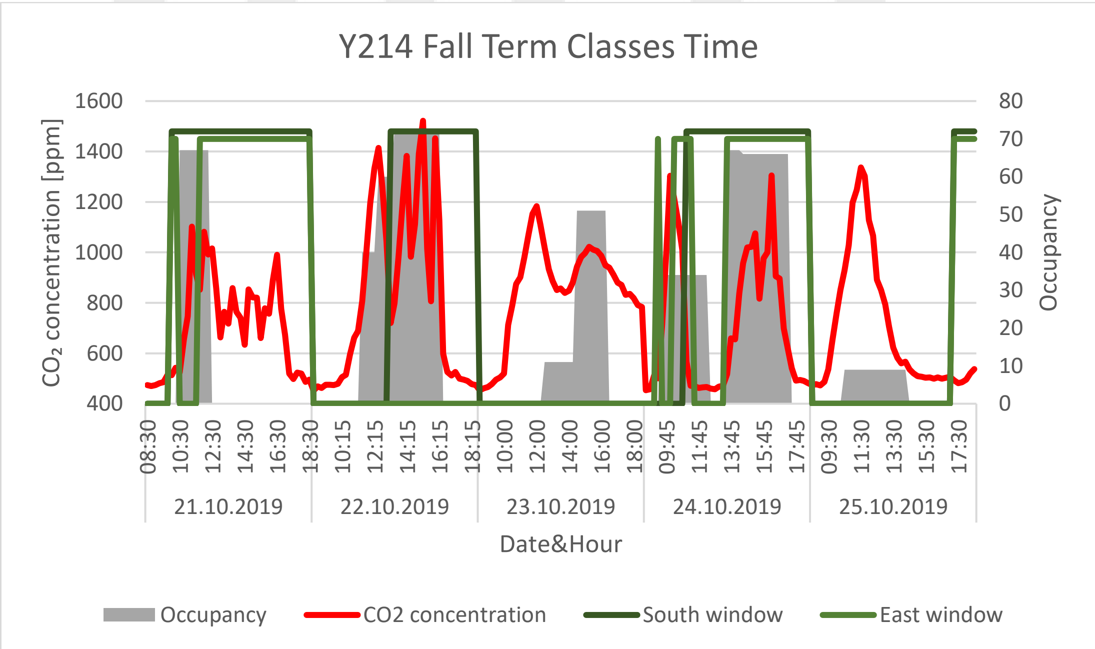

Figure 19. CO_2 Concentration and Classroom Occupancy in Y214 According to 6^{th} Week of the Fall Term

As in the final period graphs, it is seen that the CO_2 concentration increases when there are users in the classroom. However, in the graph, it was observed that there was an increase in the level of CO_2 and fluctuations in the hours when there was no use. This is because students use classes for collective study a week before the midterm exams, or compensatory lessons that are not covered in the class calendar. Also, the biggest difference compared to the final period charts is that the CO_2 concentration is always at high levels. It is seen that the value that rarely exceeded the 1000 ppm level in the final period exceeded the limit more frequently during the lesson period. The biggest reason for this is the use of classes in exams at half capacity. The number of people in the course is about twice the final period. In addition, the number of students in the finals decreases towards the end of the exam and there is usually a gap between the 2 exams. However, the number of people varies at a minimum level during the course and consecutive courses are held. This caused the CO_2 concentration to remain close to the limit in general.

As in the fall semester, the 7th week is examined in the spring semester. Figure 20 shows the relationship between CO_2 concentration and occupancy.

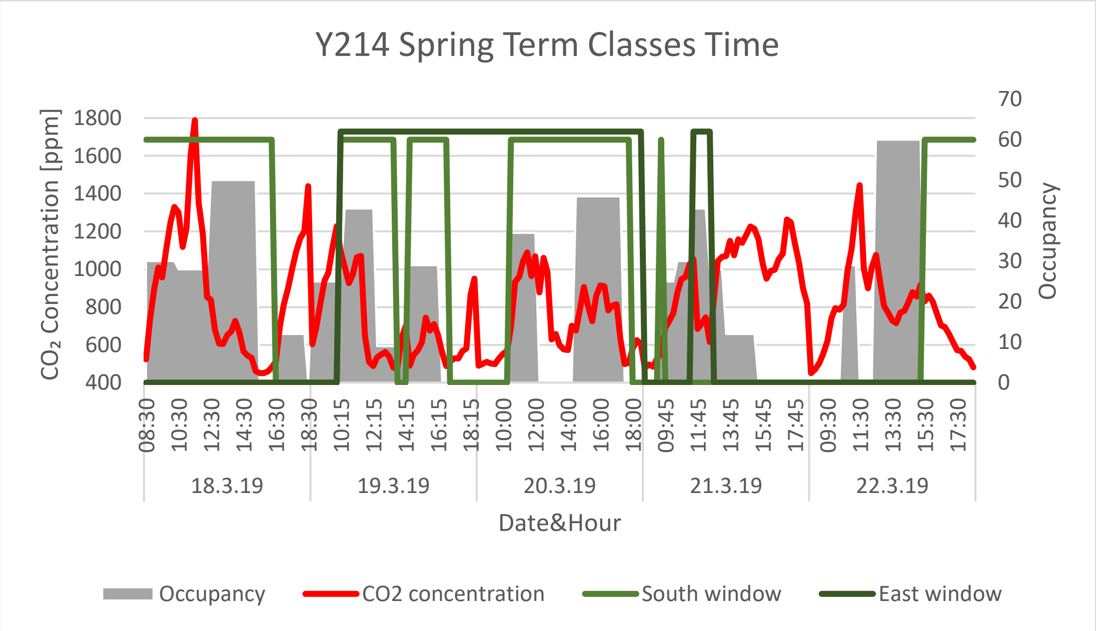

Figure 20. CO_2 Concentration and Classroom Occupancy in Y214 According to 6th Week of the Spring Term

Looking at the graphic of the spring final semester, the CO_2 concentration, which reached a maximum of 1500 ppm, reached the level of 1800 ppm in the course period. The reason for this situation is that more windows are opened in the final period and the user density is at half level.

5.1.2. The Relationship between Temperature, Occupancy and Window Opening

In this section, temperature measurement data are examined for the final and course periods of the classes. How the data of indoor temperature changes with the effect of outdoor temperature, person density, and window opening was analyzed.

In Figure 21, the analysis of the relationship between temperature, user density, and window opening of the Y214 class for the fall final period is given.

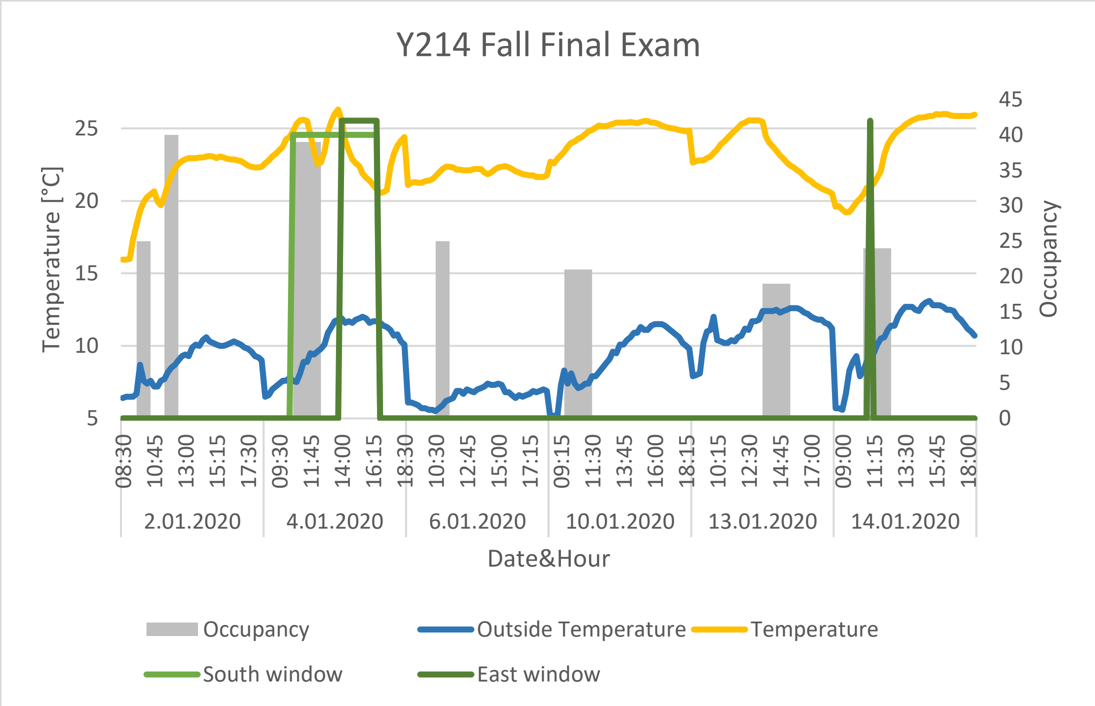

Figure 21. Temperature Values and Classroom Occupancy in Y214 for Fall Final Exam Period

When Figure 21 is analyzed, it is seen that the indoor temperature creates curves similar to the outdoor temperature. It can be said that the outside air temperature directly affects the indoor air conditions. At times when students were present in the classes, the temperature increased by an average of 3-4 °C compared to the previous situation. As expected, a sudden drop in temperature was observed as soon as the window was opened. When the single window was opened, the decrease in temperature was 2-3 °C, while in the scenario where the double window was open, this amount was 5-6 °C.

Figure 22 shows the relationship between temperature, occupancy, and window opening for the spring final period.

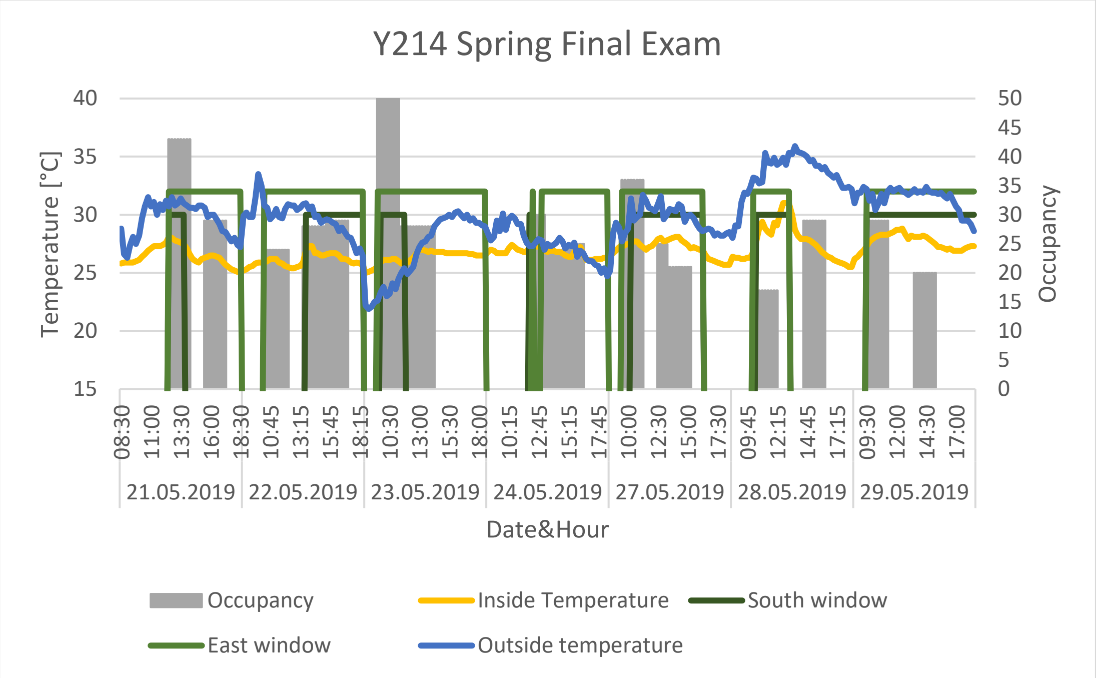

Figure 22. Temperature Values and Classroom Occupancy in Y214 for Spring Final Exam Period

In Figure 22, it is seen that the indoor and outdoor temperatures are very close. With the windows being open for long hours, an environment has been created for the temperatures in the interior and exterior to approach each other. During the exam hours, there was an increase of approximately 1.5 °C in the indoor temperature. In the absence of an exam, a graph that tends to approach the outside temperature appears.

As in Section 5.1.1, examinations were made for the 7th week of the periods. Graphs of the relations between the temperature, occupancy, and window opening of the Y214 class for the fall and spring courses are given in Figure 23 and Figure 24, respectively.

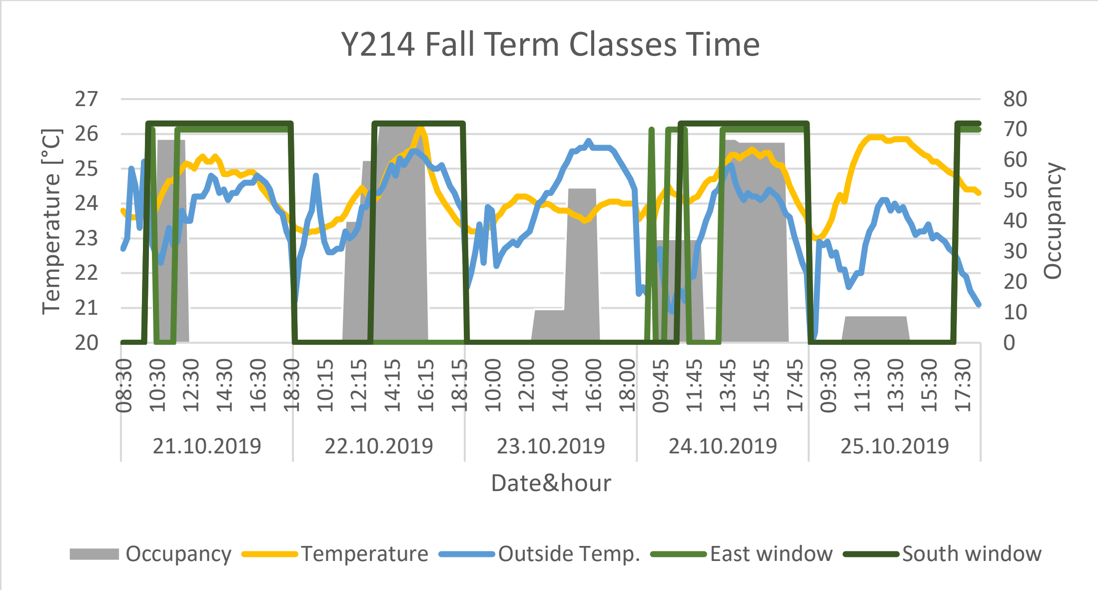

Figure 23. Temperature Values and Classroom Occupancy in Y214 According to 6th Week of the Fall Term

Generally, it is seen that indoor air temperature and outdoor air follow each other. The average of indoor and outdoor temperatures were found as 24.39 °C and 23.59 °C, respectively. Between 23.10.2019 and 25.10.2019, larger differences occurred between the outdoor and indoor air temperatures. The reason for this may be the fact that both windows are closed these days so that they are isolated from the outside temperature. When the window is opened, the indoor air temperature is balanced with the outdoor temperature with a fast slope.

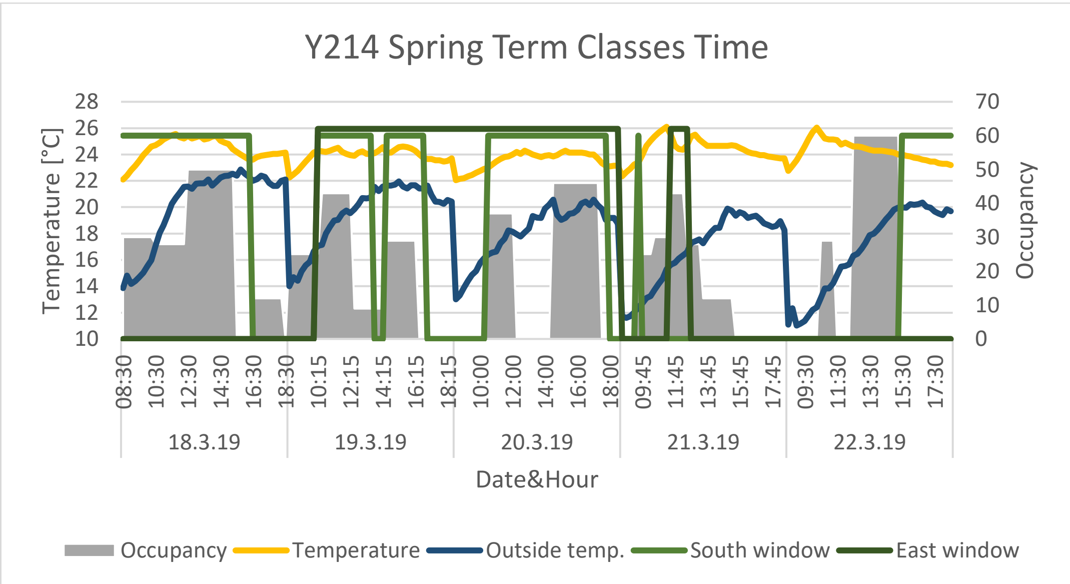

Figure 24. Temperature Values and Classroom Occupancy in Y214 According to 6th Week of the Spring Term

Indoor air generally has a temperature curve that follows the change of outside air. However, temperatures are not close to each other as in the fall period. Because, the outdoor temperature has decreased by 7 °C compared to the fall period and the heating system is working. The average value of the indoor air temperature is 24.27 °C while the outdoor air has a value of 16.93 °C. When the windows are open, the difference decreases, and when closed, it increases. It was found that when both windows were open for a long time, for example, on 20.03.19, the indoor air temperature did not fall below the comfort level. In addition, the average indoor air temperature is 4 °C above 20 °C, which is the comfort condition for the heating period. For these reasons, it can be said that the heating system operates at high capacity.

5.2. Energy Consumption Analysis

Since the heating and cooling processes in the T building are provided by VRF system, a large part of the electricity consumption is caused by the HVAC system. The mechanical measurements of the analyzers in the building show the electrical energy consumed by the HVAC system. In this section, electricity consumption is examined according to the operating conditions.

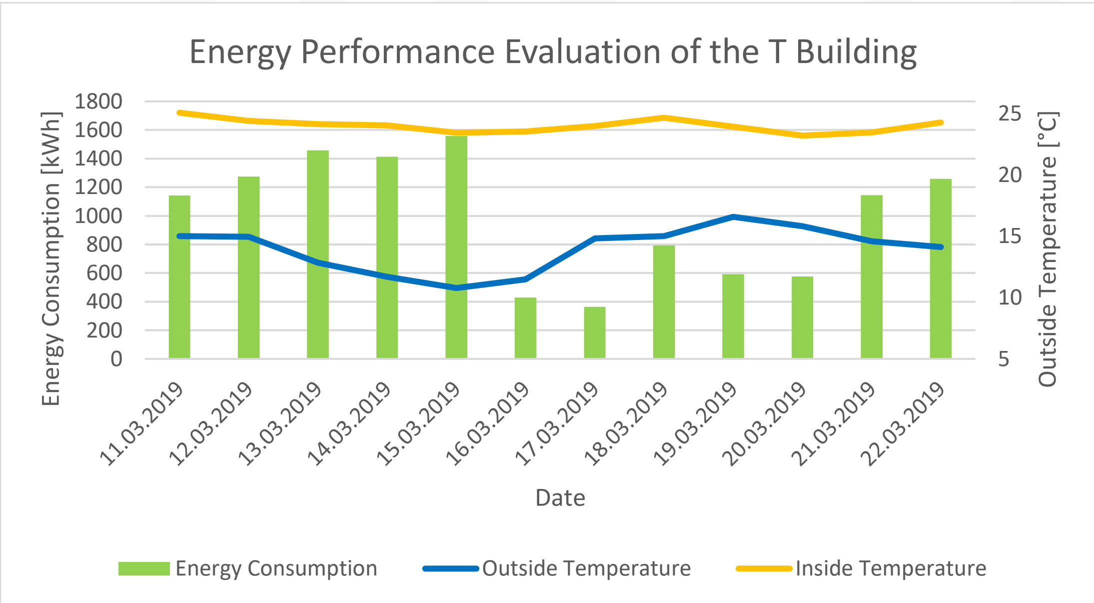

Figure 25. Energy Performance Evaluation According to Heat Mode Change in the T building

Figure 25 shows the energy consumption throughout the T building in a 2-week period. (Through Monday to Friday). In the week starting on 11.03.2019, the mode of the

HVAC system is programmed for automatic operation at 7:30 in the morning as in previous weeks. In the week beginning on Monday, 18.03.2019, the automatic operation setting was closed and the system was started to be controlled manually. The reason for this process is the increase in the average of outside temperature. When the daily consumption values are collected for both weeks without taking into account the weekends, the result is: 6848.81 kWh in the first week and 4363.55 kWh in the second week. In summary, just turning off the automatic operation setting of the system achieved a 36.2% reduction in energy consumption.

Table 14. 6-Week Time Monitoring of System Activation Mode Change

	The day that week begins	Total energy consumption [kWh]	Outside temp. average [°C]
Auto	25.02.2019	10734.53	8.77
	4.03.2019	6905.71	14.49
	11.03.2019	6848.81	13.06
Manuel	18.03.2019	4363.55	15.23
	25.03.2019	5404.11	13.44
	01.04.2019	4752.21	15.01

The graphic above summarizes the week after the automatic system was shut down for the first time. In this process, the increase of outside temperature also has an effect on the decrease of energy consumption. Table 14 examines 3 weeks before and after automatic operation is turned off. Total energy consumption values and average outdoor temperature values are given for these 3 weeks. Looking at the dates of 15.03.2019 and 29.03.2019, it was observed that the outside temperature averages were very close for these two days. Energy consumption is 6848.81 kWh and 5404.11 kWh, respectively. In this case, it can be said that for the cases where the effect of the outside temperature factor impact is less, approximately 21% energy reduction is achieved by manually controlling the system.

5.3. CO_2 Concentration Analysis

5.3.1. General Measurement Analysis

Table 15 summarizes the CO_2 concentration analysis for the course period. When creating the analysis table, only the times in the classes were taken into account. Similarly, Table 16 was created by taking into account only the final exam times in the classrooms. As stated in section 4.1, the optimum CO_2 concentration value in the classes should be 1000 ppm. Looking at the course period, the most inefficient class in terms of CO_2 concentration is T212. Class T212 was found to be 40% below 1000 ppm. This is not suitable for comfort conditions, but it has been observed that the values that fall below 1500 ppm in the same class are 65% and this is at an acceptable level.

Table 15. CO_2 Concentration Analysis for the Education Period

	18-19 Spring Term Classes			19-20 Fall Term Classes		
	<1000 ppm	<1500 ppm	>2500 ppm	<1000 ppm	<1500 ppm	>2500 ppm
T-1B10	66.37	91.96	1.04	65.09	95.71	0.11
T212	56.95	83.29	1.45	40.22	65.02	4.53
T214	67.21	88.61	0.38	61.30	85.54	1.20
T514	75.29	91.97	0.19	55.48	77.62	3.10
Y213	72.07	91.13	0.40	75.27	93.61	0.19
Y214	63.70	89.87	0.27	63.65	91.35	1.59

Table 16. CO_2 Concentration Analysis for the Final Exam Period

	18-19 Spring Final Exam				19-20 Fall Final Exam			
	<1000 ppm	<1500 ppm	>1500 ppm	**Volume/ occupancy**	<1000 ppm	<1500 ppm	>1500 ppm	**Volume/ occupancy**
T-1B10	46.92	90	10	**6.79**	16.67	83.33	16.67	**7.08**
T212	31.45	63.71	36.29	**8.13**	21.77	52.38	47.61	**6.89**
T214	45.74	64.89	35.11	**9.95**	69.23	90	10	**10.6**
T514	50	80.26	19.74	**11.43**	51.04	84.37	15.63	**12.82**
Y213	100	100	0	**7.51**	62.22	91.11	8.89	**22.0**
Y214	79.84	98.45	1.55	**11.74**	41.18	90.20	9.80	**12.58**

In the 2018-2019 final period, it is seen that the CO_2 concentration is below 1000 ppm in the Y213 class. The reason for this situation is that there is only one exam in that class and the number of people in this exam process is below the user capacity of the class. The usage dates of the classes in the course and final period and how many people use it can be found in the class programs in Appendix 1.

In addition, when Table 16 is examined for both of the final periods, the classes with the highest CO_2 concentration are T-1B10 and T212. The reason for this may be the ratio between the class volume and the number of occupancy. The average volume per user in these two classes is around 7 m^3. This amount is low compared to other classes. When the volume ratio per user for the final period given in Table 16 are analyzed, it is seen that there is a difference of 14 m^3 between the two periods for the class 'Y213'. The reason for this is that only one exam is held in this class during the 18-19 final semester and the number of people in this exam is higher than the class volume. Although the volume / occupancy ratio in spring and fall periods is close to each other in T-1B10 class, CO_2 concentration values below 1000 ppm are higher in the spring period. It is assumed that this is due to the fact that the windows are more open than the fall season and the CO_2 concentration decreases in the spring period. Although the volume per user rate is low, the CO_2 concentration remained at the desired level. For this class, it will be more realistic to consider the data of the per capita volume ratio in the 19-20 final period. It is clearly seen that in classes with the minimum volume ratio other than Y213, the CO_2 level is above the limit. The graph created with the average values of both final periods using the calculated data in Table 16 is presented in Figure 26.

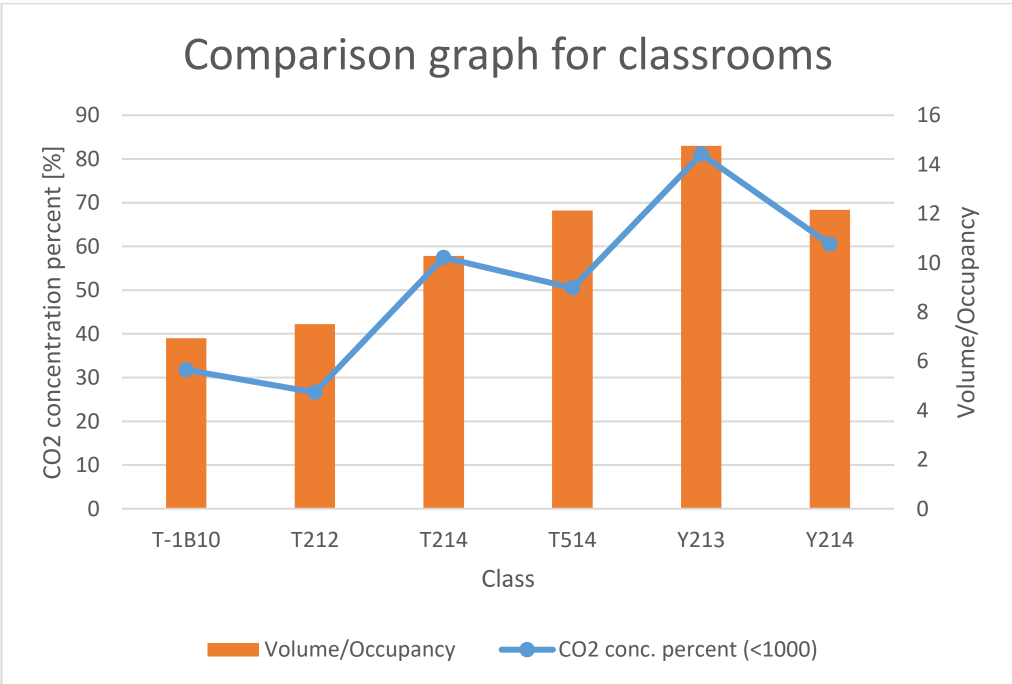

Figure 26. Comparison between Distribution of CO_2 Concentration for Smaller than 1000 ppm and Volume-Occupancy Ratio

As seen in Figure 26, when the volume / occupancy ratio increases, the percentage of CO_2 concentration in the class which is below 1000 ppm also increases. However this growth is still under the limit of 1000 ppm.

5.3.2. CO_2 Concentration Calculation

A loop was created by using Eq.2 presented in Section 4.2 of MATLAB software. Thanks to this software, CO_2 concentration values in the classes have been estimated. A class with the same floor and direction was chosen from Y and T buildings (Y214 and T214). In these classes, CO_2 concentration variation is modeled by using the loop in MATLAB software. In the study, the air flow rate was not regularly measured and recorded. Therefore, the air flow rate is not known precisely. While modeling, using the 'Eq.3' mentioned in Section 4.3, the air flow rate and ACH were calculated.

In this section, firstly, the CO_2 intensity values will be presented according to the ACH change of the classes. Air velocity measurement was made in 2 selected classes, when there was no use and at a time other than the period under examination. These measurements were made manually to be used as an approximate value in the calculation. Secondly, calculated and measured CO_2 concentration values are compared by using air velocity measurement results.

The number of people, one of the parameters that most affect the CO_2 concentration, is also not measured regularly. For this reason, examinations were carried out considering that most of the enrolled students will attend the final exam. However, students do not stay in the classroom during the entire exam period. As a result of the interviews with the examiners, how long after the students started leaving the exam was evaluated and an approach was developed. Exams usually take 2 lessons (110min) and after about 45 min, 10% of the participants leave the class. And in the last 15 minutes of the exam, 10% of the class is still in the class. The number of people in the class is determined to fit the rates shown.

In each class, 3 exam times with the same number of people and with the same exam time were chosen on different days. The window opening situation is different in each of these 3 exams. Thus, the effect of window opening on the amount of CO_2 is examined. Date, time, number of users, window opening status and average CO_2 concentration values of the exams are given in Table 17 and Table 18.

Table 17. Exam Date, CO_2 Concentration and Window Opening Information in Y214 for 3 Exams

Y214				
Exam Date	Exam Hour	Occupancy [ppm]	Window Condition	CO_2 Conc. Average [ppm]
21.05.2019	15:30-17:30	29	1 window open	795.12
28.05.2019	14:30-16:30	29	no window open	1348.25
29.05.2019	9:30-11:30	29	2 window open	619.5

Table 18. Exam Date, CO_2 Concentration and Window Opening Information in T214 for 3 Exams

T214				
Exam Date	Exam Hour	Occupancy [ppm]	Window Condition	CO_2 Conc. Average [ppm]
27.05.2019	11:00-12:30	29	1 window open	946.71
23.05.2019	15:00-16:30	29	no window open	2118
21.05.2019	15:00-16:30	30	2 window open	815.57

- *CO_2 concentration comparison according to ACH rate:*

According to (Krawczyk et al., 2016) and (Johnson et al., 2018), the air exchange rate (ACH) per hour in classes should be between 1 h^{-1} and 4 h^{-1}. First, the CO_2 concentration change charts were created by selecting the ACH value between 1 h^{-1} and 4 h^{-1} in the studied classes. Later, these curves were examined and ACH value was found to provide the level of CO_2 concentration in the standards. The change of ACH and CO_2 concentration is indicated in the graphs below for each class and different window openings. Detailed interpretation of these graphics was made according to the curves created by the air flow.

The fact that the number of open windows in the classrooms is different changes the amount of fresh air entering the interior environment. However, this situation varies according to the weather conditions. Parameters such as the amount of CO_2 in outside air, wind speed and direction, temperature and humidity of the air constantly change. Outdoor parameters on the date selected for calculations may not be the same as those on another date and may vary greatly depending on the number of open windows in the selected class.

While creating all the graphs in this study, the weather conditions were considered constant and the values were calculated accordingly. Errors caused by outside weather conditions are neglected.

For the cases of Y214 class 1 window open, 2 window open and no window open, ACH rate and CO_2 concentration change curves are given in Figure 27, Figure 28 and Figure 29 respectively.

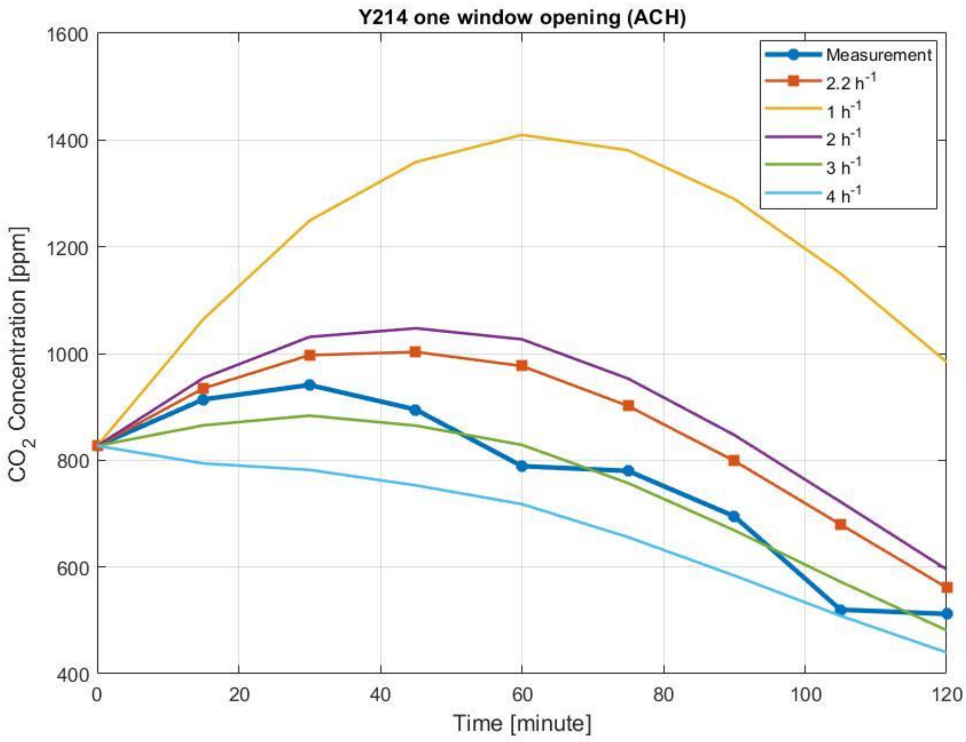

Figure 27. CO_2 Curves for Different ACH Values in Y214 with One Window Opening

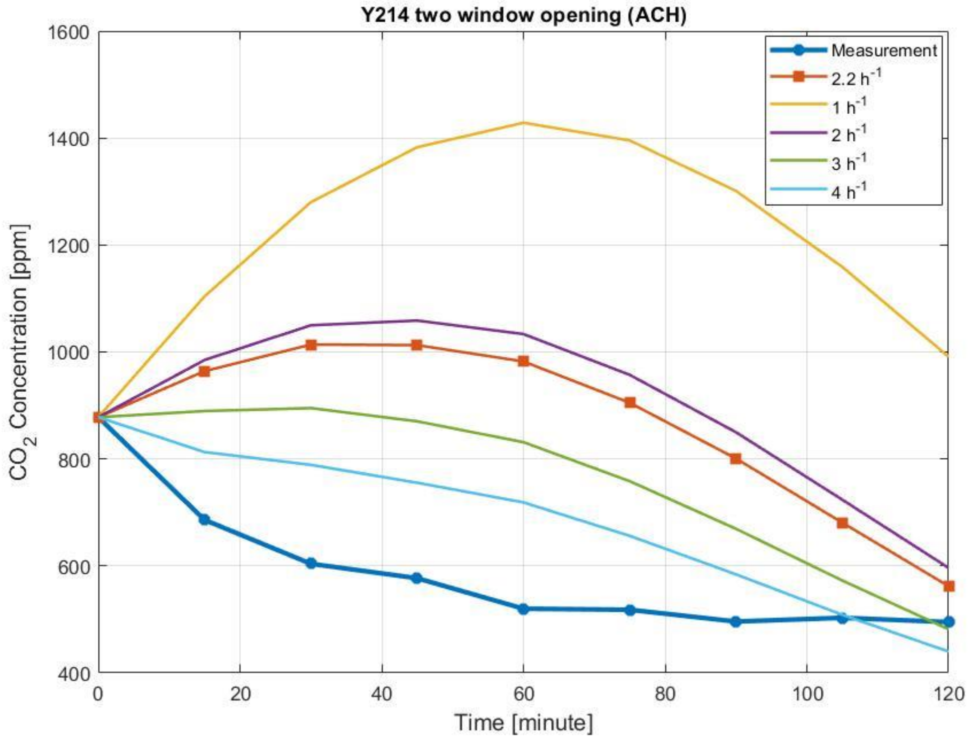

Figure 28. CO_2 Curves for Different ACH Values in Y214 with Two Window Opening

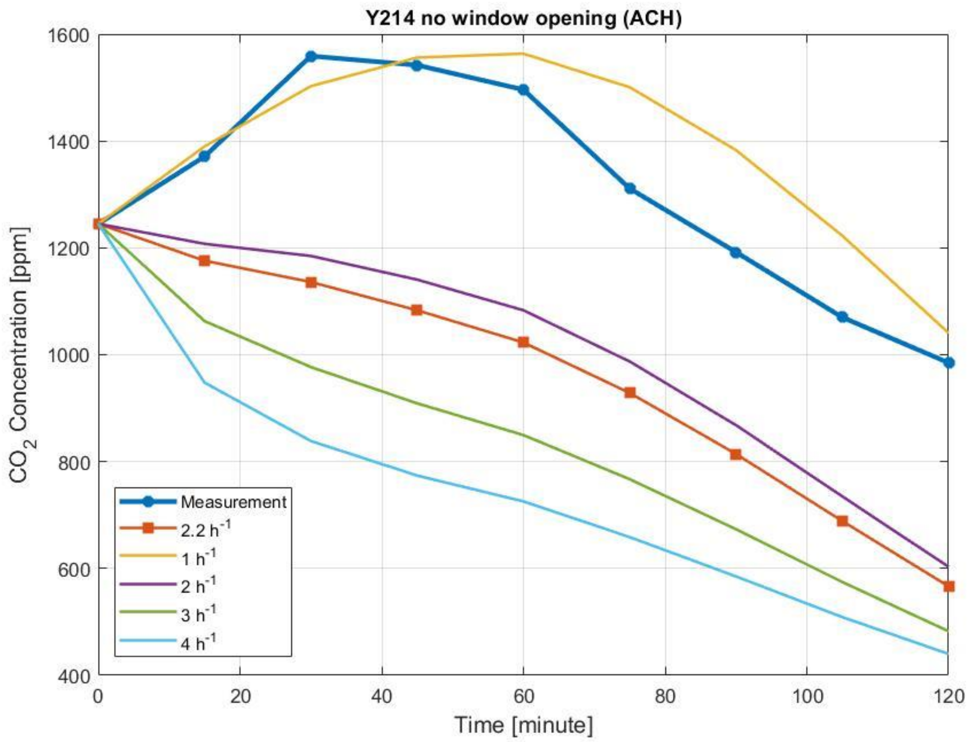

Figure 29. CO_2 Curves for Different ACH Values in Y214 with Zero Window Opening

The ACH value shown in red in the graphs examined is the value required for the CO_2 concentration of the class to remain at the limit level. This value, which is 2.2 h^{-1}, is valid for an exam with 29 users. If the initial CO_2 concentration is below 1000 ppm, no class exceeded for 2.2 h^{-1}. However, when there is no window opening, the initial CO_2 concentration is approximately 1250 ppm, so it took 1 hour to decrease to the limit level.

The ACH rate and CO_2 concentration change graphs created for class T214 are given in Figure 30, Figure 31 and Figure 32, respectively, for situations with 1 window open, 2 windows open and no window open.

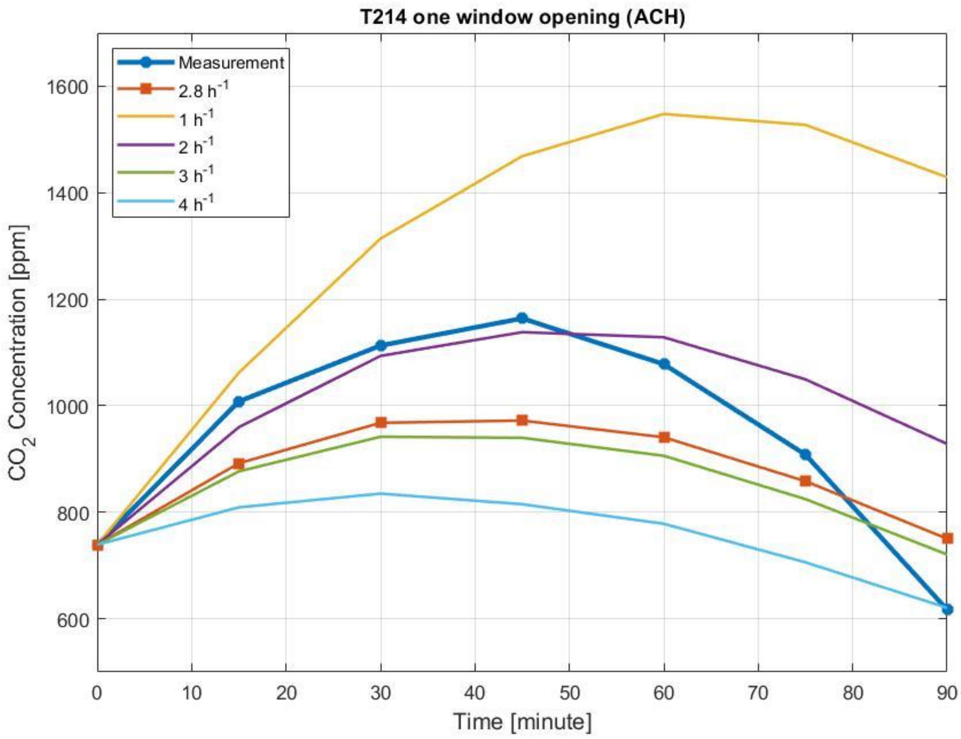

Figure 30. CO_2 Curves for Different ACH Values in T214 with One Window Opening

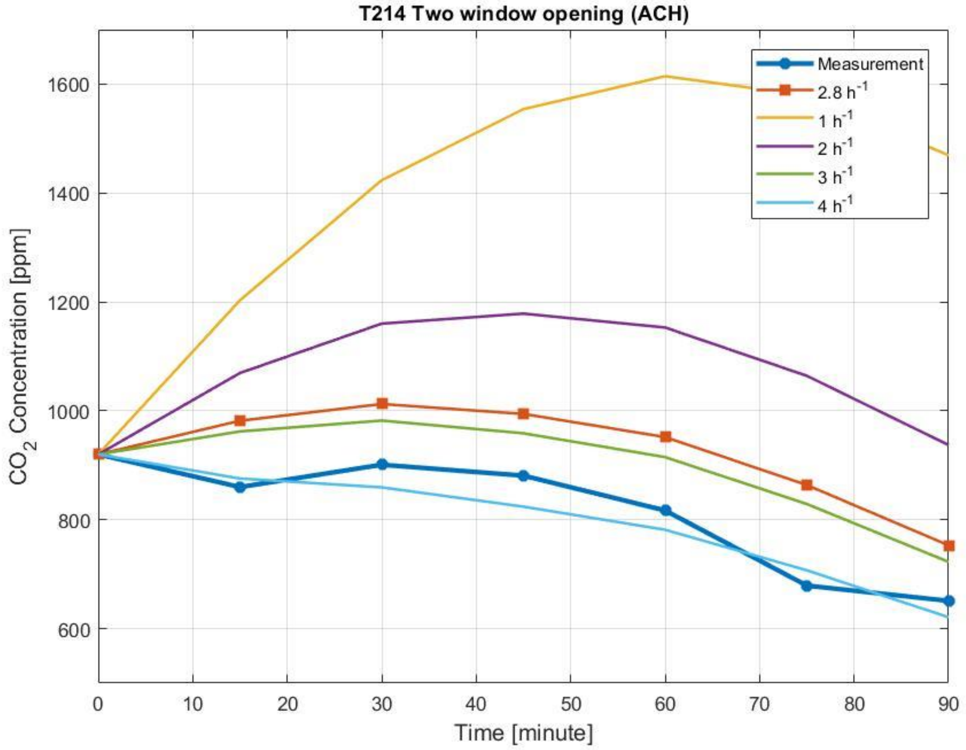

Figure 31. CO_2 Curves for Different ACH Values in T214 with Two Window Opening

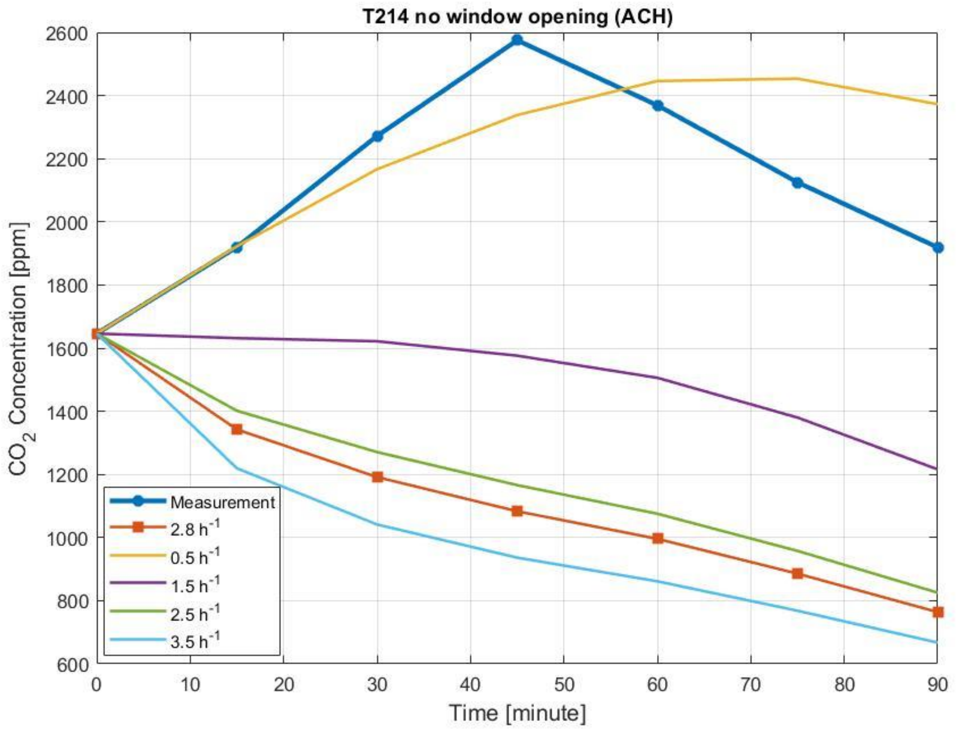

Figure 32. CO_2 Curves for Different ACH Values in T214 with Zero Window Opening

For the T214 class, the optimum ACH value was found 2.8 h^{-1} in a 29-person exam. This value is shown in red in each chart. The 1000 ppm limit has not been exceeded in cases where windows are open. However, in Figure 32, where the CO_2 concentration initial value is greater than 1000 ppm, 1 hour was required to decrease to the limit level.

- *CO_2 concentration comparison according to air flow:*

The graphics created according to the air flow rate values found by looking at the results of the air velocity measurement done in the classes are given in this section. The Q value may differ depending on the wind speed on the day of measurement. Therefore, differences may occur between the two curves in the graphs showing the calculation and measurement results. In addition, the fact that the number of people is not known and given as an estimated input may cause differences between these curves.

In the measurements made in the condition with 1 window open in class Y214, the air flow rate value varies between 0.35 m/s and 1.84 m/s. The average of measurements taken from 10 locations was found to be 0.80 m/s. The air inlet area of the window is 0.30 m^2. Thus, the air velocity and area were multiplied and the air flow rate was found to be 0.24 m^3/s. In addition, as a result of measurements made with a window and door open, the average air flow rate was found to be 0.26 m^3/s. The calculation and measurement results found using these values are given in Figure 33. In addition, the air flow value corresponding to the optimum ACH value (2.2 h^{-1}) found for this class is 0.1925 m^3/s. This Q value is also indicated in red in each graph.

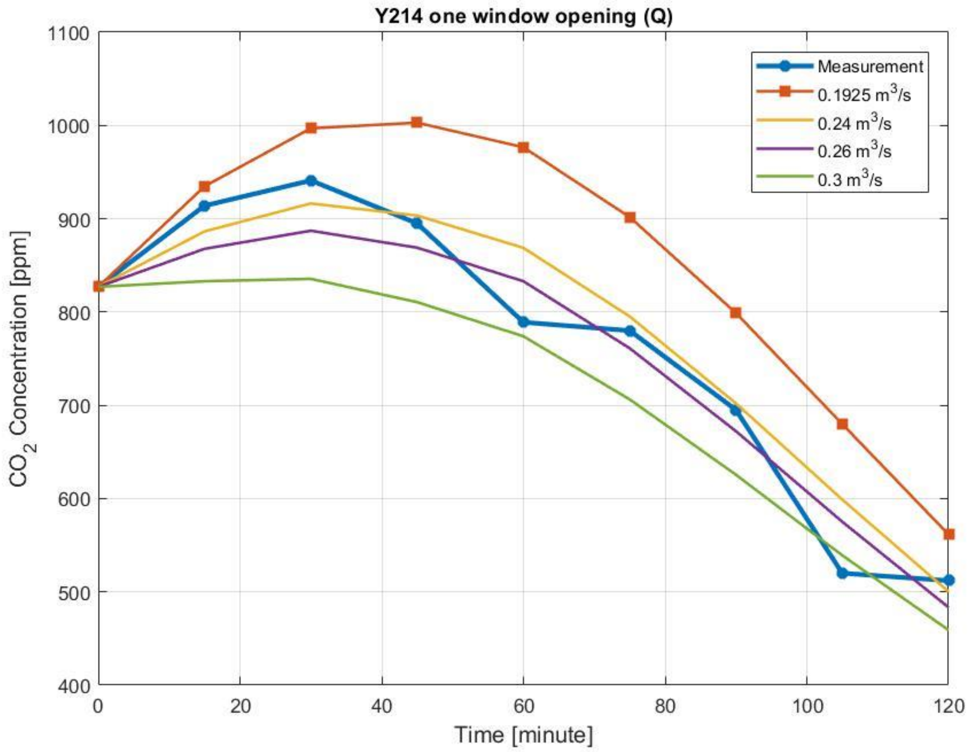

Figure 33. CO_2 Curves for Different Q Values in Y214 with One Window Opening

When the graphic is examined, it is seen that when 1 window is open, there are 29 people in the class and sufficient ventilation is provided and the comfort conditions specified in the standards are not exceeded.

The measured air flow rate ranges from 0.56 m/s to 4.17 m/s when 2 windows are open in the classroom. The air flow velocity from the average of the measurements made was found to be 1.76 m/s. Thus, the Q value was calculated as 0.52 m^3/s. In addition, as a result of measurements made with 2 windows and class doors open, the Q value was found to be 0.8 m^3/s. When the calculation result made only in the condition where the windows are open is examined ($Q = 0.52\ m^3/s$), it is seen that the calculation curve shows a higher ppm level than the measurement curve. These curves are shown in Figure 34. However, when the situation where the door is also open is observed, a lower CO_2 level was observed than the previous measured values. As a reason for this situation, it can be shown that the door may be opened at certain intervals, the number of people may be lower, or it may be a day with more air inlet flow than the measured day.

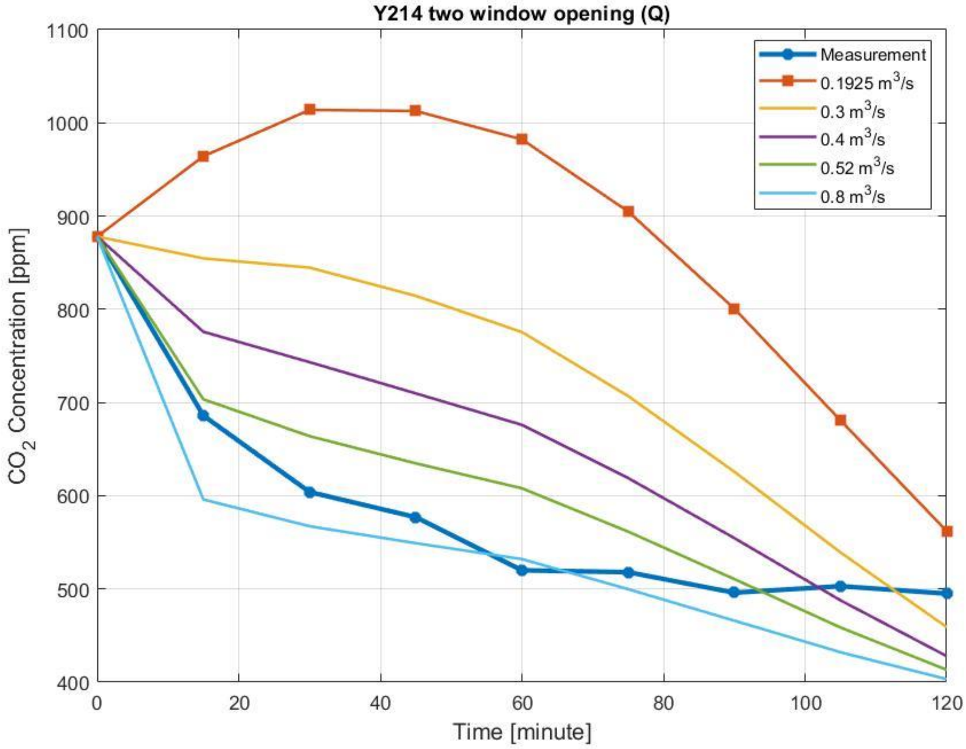

Figure 34. CO_2 Curves for Different Q Values in Y214 with Two Window Opening

As expected, the level of CO_2 concentration in the class did not exceed the limit value when 2 windows were open.

In the measurements made when no window is open in the classroom, the flow rate in the environment was found to be zero, but the minimum measurement value of the device used is known to be 0.3 m/s. Curves are presented in Figure 35. When the value of Q was accepted as 0.1 m^3/s, it was seen that the results match the measurement values. Consequently, when the window is not open in the classroom, it seems that the ventilation quality is not sufficient and the CO_2 level rises above the limit value.

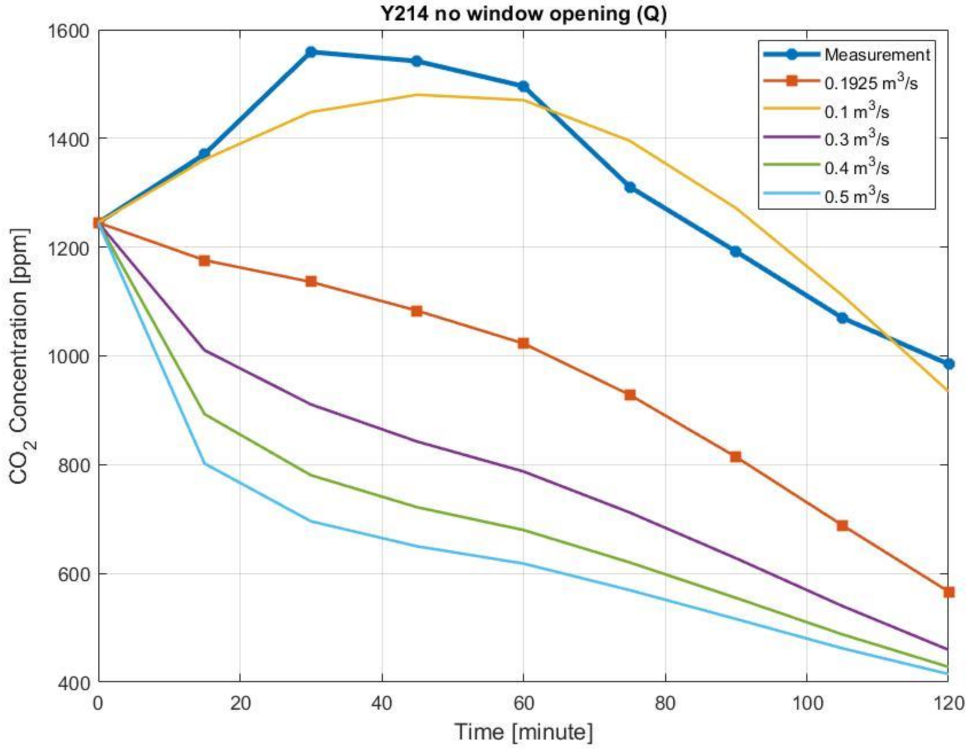

Figure 35. CO_2 Curves for Different Q Values in Y214 with Zero Window Opening

The air flow rate values required to keep the CO_2 concentration in line with the standards were tested. The calculation was made by changing the Q value between 0.1 m^3/s and 0.5 m^3/s and the results are shown in Figure 35. When the value corresponding to ACH (0.1925 m^3/s) was chosen as the air flow rate, it was seen that the CO_2 concentration was reduced to the limit level after 1 hour. When this value is accepted as 0.3 m^3/s, CO_2 concentration in the class has decreased to 1000 ppm level in only 15 minutes.

The changes of CO_2 concentration prepared for the class T214 according to the air flow rate are given in Figure 36, Figure 37 and Figure 38, respectively.

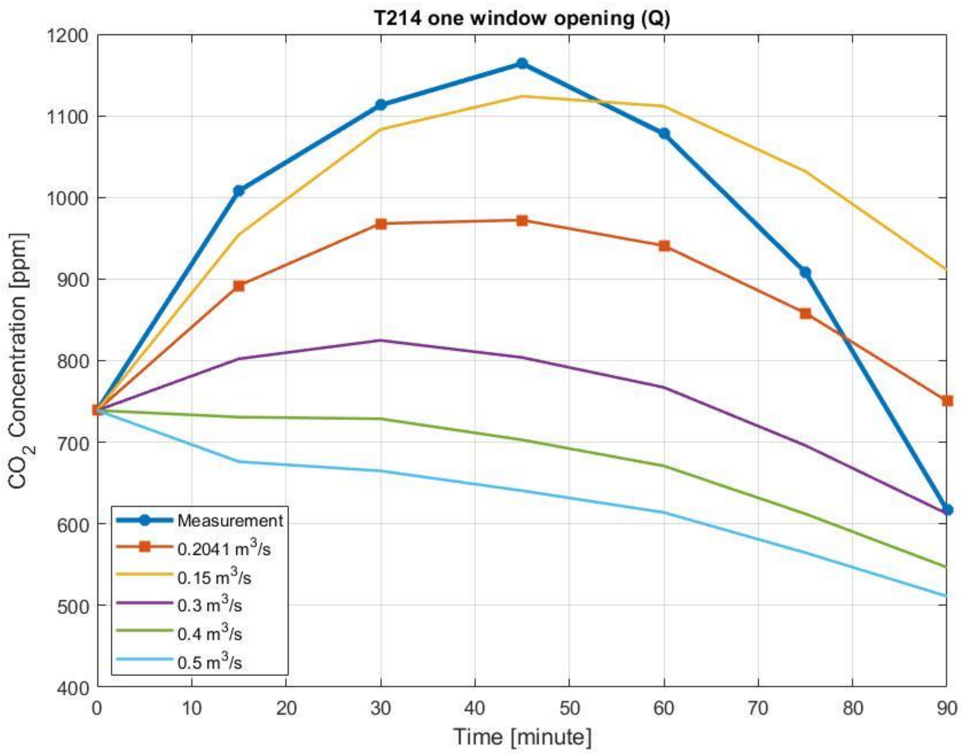

Figure 36. CO_2 Curves for Different Q Values in T214 with One Window Opening

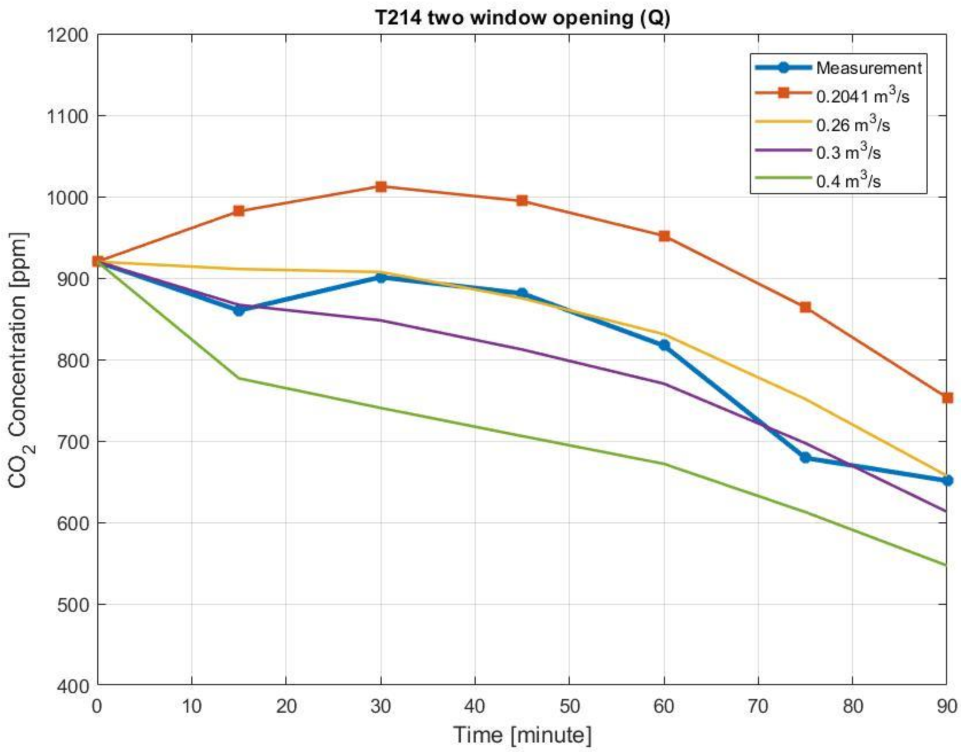

Figure 37. CO_2 Curves for Different Q Values in T214 with Two Window Opening

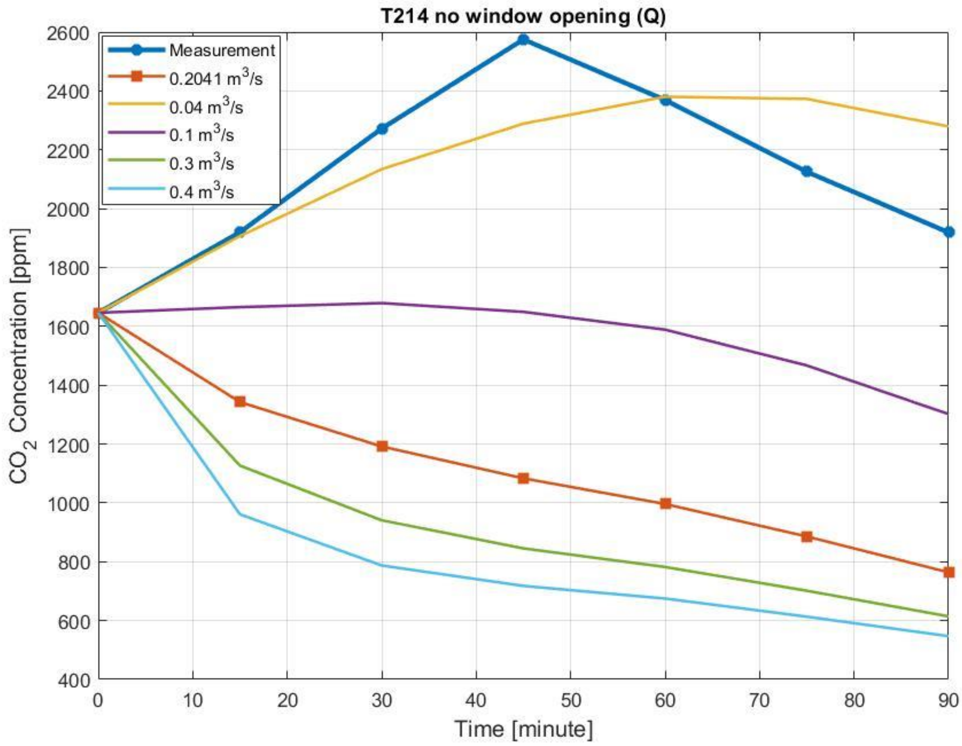

Figure 38. CO_2 Curves for Different Q Values in T214 with Zero Window Opening

- *Evaluation of ACH values according to class capacity:*

All of the examinations in this section were made for the final period. The reason for this is that the prediction of the number of students in the class can be made closer to reality and the exam times are known clearly. The duration of the courses in the education period may vary according to the subject of that week and students may not participate fully. However, during the exam periods, classes are used by less than their actual capacity. Therefore, a re-evaluation was made for the class named T214 from the examined classes. The reason for choosing T214 is that the ventilation system is located throughout the T building. Thus, the capacity adequacy of the ventilation system has been benchmarked. In the T214 class, there are 3 vents that blow fresh air inside and 3 exhaust the air inside. Each of these vents has an adjustable airflow rate from 200 m^3/h to 500 m^3/h.

First of all, the most capable course was found by looking at the class schedule of the T214 (Appendix 1). The recorded measurement results were examined and a range in which all windows were closed during this lesson was selected. The air flow rate of the ventilation system in the class is modeled from the lowest level (600 m^3/h) to the highest level (1500 m³/h). Curves showing the change of CO_2 concentration in the environment according to the air flow rate are given in Figure 39. In addition, an air flow rate (2000 m³/h) above the system capacity is shown in the graph to interpret the system capability.

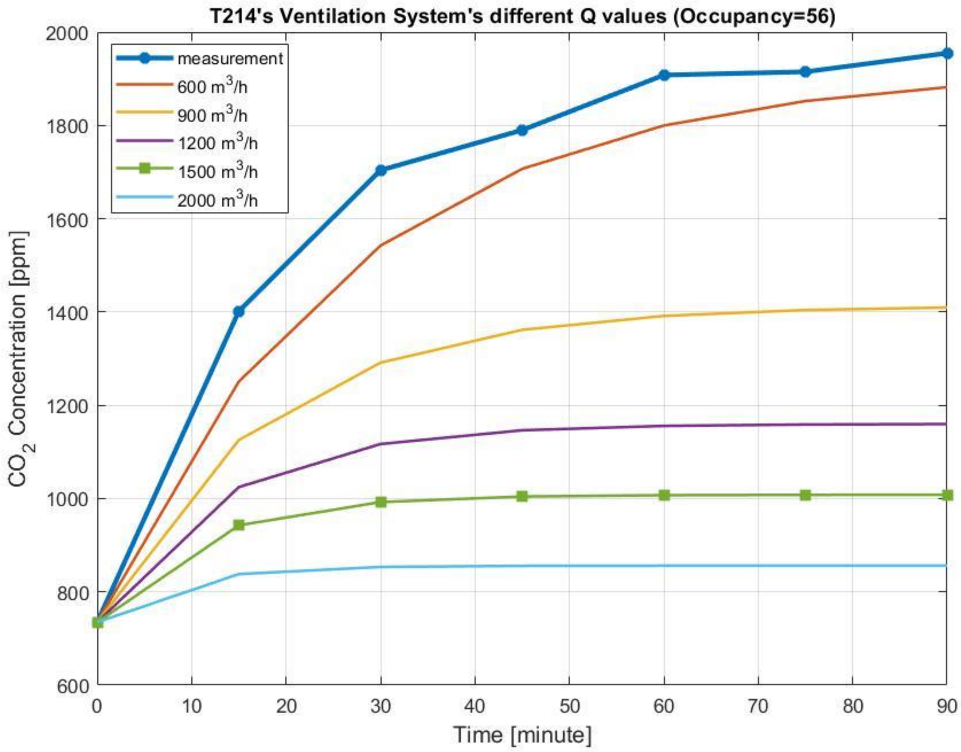

Figure 39. T214 Ventilation System's Different Q values for 56 user occupancy

While creating the chart in Figure 39, the measurement data of the course, which started at 14:30 on 15.02.2019, was used. The number of students enrolled in this course is 56. It was observed that the windows were closed during the 90-minute lesson. The CO_2 concentration measured in the classroom has exceeded 1800 ppm. However, when the curves were examined, it was seen that the CO_2 level conforms to the standards level when the system operates at full capacity. Since the exterior louvers of the ventilation system are attached to the facade, it has been determined that there is a problem of water intake on rainy days. For this reason, the system is not operated on rainy days. The reason for the increase in CO_2 concentration measured in this class may be that the system is not operated due to rain. In addition, it was observed that when the ventilation system is operated at minimum flow rate, values close to the measurement data are formed. Considering this situation, it can be said that the ventilation system is in operation but it operates at low capacity.

For the same class, the actual user capacity of the class was taken into account and CO_2 concentration change curves were modeled at different flow rates. These curves are shown in Figure 40.

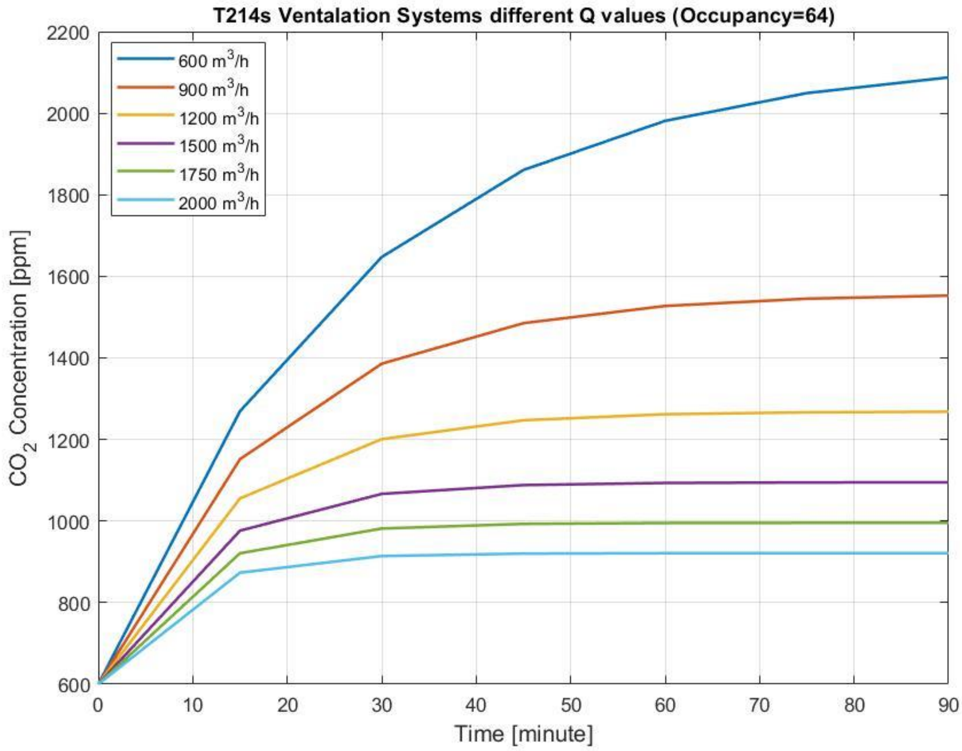

Figure 40. T214 Ventilation System's Different Q values for 64 user occupancy

As a result of modeling, the number of people was fixed at 64, the windows were closed and the initial CO_2 concentration was 600 ppm, and the maximum capacity of the ventilation system was determined as 1500 m³/h. Looking at this value, it was seen that the air flow was not sufficient. When the air flow rate is 1500 m³/h, the CO_2 concentration has increased to a maximum of 1100 ppm. For some sources, this is an acceptable level (Almeida and Freitas, 2014, Johnson et al., 2018, Bernardo et al., 2017). The air flow rate required for the CO_2 level not to exceed 1000 ppm was found to be 1700 m³/s in conditions where the class chosen as the subject was 262 m³ and accommodated 64 people.

5.4. Evaluations of Survey Results

PMV values obtained from the questionnaires applied in the classes are presented in this section. The surveys were conducted in May for the spring semester and in

October for the fall semester. There are a total of 1198 questionnaires answered by the students participating in the course. 765 of the surveys made correspond to the periods examined in this study. 90 of them were carried out in May, 675 of them were carried out in October. 48% of the surveyed users are between 21-23 years old, 39% are between 18-20 years old, and more than half (55.9%) are female students. The PMV curves created with the responses of the participants regarding their thermal sensitivity are given in the graphs below for both survey periods. Figure 41 contains the results of the survey conducted in the spring term.

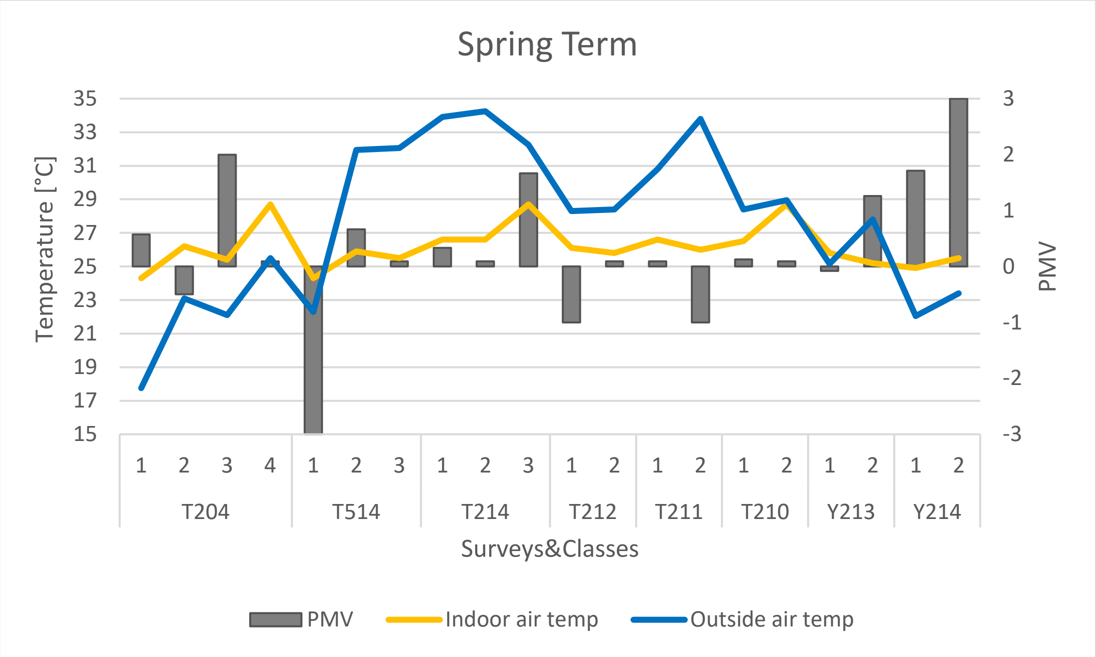

Figure 41. Survey Results of Classrooms on Spring Term

When the change of PMV values according to the indoor temperature is examined, it is seen that PMV value increases when the temperature increases and PMV value decreases when the temperature increases. However, exceptional cases have been observed. For example, in the second experiment in Y214, the participant reported the environment as very warm, but it should be considered that the number of respondents was only 1. This problem exists throughout the spring semester. For this reason, the number of surveys is far below the fall period and there are many results where PMV reaches the limit values (too hot and too cold). As a result of the survey conducted in the spring term, the average PMV value was found to be 0.25. According to the standards, PMV value should be between -0.5 and 0.5 in educational buildings (ASHRAE, 2010). The calculated average value is within this range.

The results of the survey conducted in the fall term are given in Figure 42. In this period, the number of participation in the survey is above expectations. Therefore, PMV values did not reach very hot and very cold limits. There were not very high differences in indoor air temperature changes.

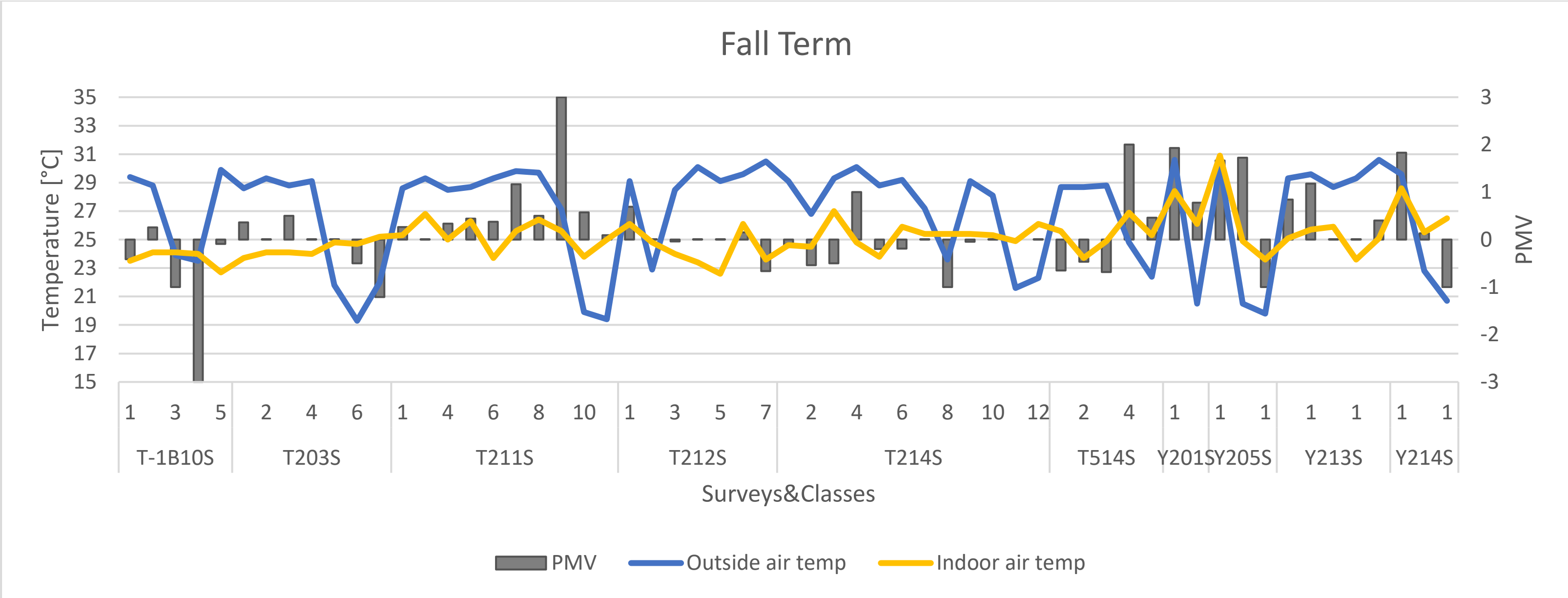

Figure 42. Survey Results of Classrooms on Fall Term

The PMV average value was found to be 0.13 and this value is within reasonable limits. Thus, it can be said that the users are provided with thermal comfort.

CHAPTER 6
CONCLUSION

As a result of the rapidly increasing developments in the field of technology on a global scale, the energy needs of all countries increase. Population growth, industrialization, increase in national income, etc. time spent in buildings has increased. This situation also increased the interest in energy efficiency and comfort levels of buildings. Approximately more than half of the energy consumption in buildings arises from HVAC systems. It is very important not to compromise on comfort conditions while reducing consumption from HVAC systems. In this study, examinations on energy consumption and indoor air quality in education buildings were conducted. Firstly, temperature, CO_2 concentration and window opening were measured for 12 months in selected classes. During this process, the amount of energy consumed by school buildings was also recorded. In order to evaluate the indoor air quality, a loop was created in the MATLAB software program to estimate the CO_2 concentration variation. In addition, a survey study was applied to verify thermal comfort. Then, the results from the analyzes are presented. The results obtained by examining the measurements made in the classes and the energy consumption data are as follows:

- The CO_2 concentration in the environment changes rapidly according to the window opening and the person density in the classroom. It was observed that there was a 50% decrease in the level of CO_2 concentration by opening the windows when the occupancy was constant for the same class. This decrease in CO_2 concentration was found by comparing the situation where no windows were open and the situation where 2 windows were open.
- It has been observed that the indoor air temperature of the classes is generally 1-2 ^{o}C above the specified standards. The temperature, which is at a normal level when there are no users in the class, rises above the normal with the increase of occupancy. The indoor air temperature does not decrease below the comfort conditions when the windows are open. The absence of a decrease in

temperature means that the heating system is working more than necessary.

- Energy consumption reaches its peak level as expected in the coldest and hottest months. In addition, the operating condition of the HVAC system is very effective in changing the amount of consumption. The HVAC system is usually set to activate automatically half an hour before the start of the working hour. Thus, when the working hours begin, thermal comfort is provided. When the automatic operation setting of the HVAC system is disabled and the system is turned on and off manually, a 36% decrease in energy consumption has observed. The reason for this decrease is not only the change of the operating condition, but also the change in the outside temperature.
- For the weeks when the outside temperature is the same, by switching the HVAC operating condition to manual, a 21% energy decrease has been achieved in the total weekly energy consumption.
- CO_2 concentration is below 1000 ppm on an average of 66% of all classes in the spring semester. This rate is 60% for the fall semester.
- Classes with low volume/occupancy ratio were found to have a higher level of CO_2 concentration.

The results of the CO_2 concentration variance estimation made by computer software are as follows;

- Air change rates (ACH) were found for 2 sample classes (Y214 and T214) from each building to keep the CO_2 concentration below 1000 ppm. The ACH value is 2.2 h^{-1} for Y214 and 2.8 h^{-1} for T214.
- CO_2 estimation curves are created by using the air flow rate found by the air velocity measurement results made in the classes. These estimation curves were consistent with the measurement results.
- As a result of the estimation of CO_2 concentration in class T214, taking into account the course period with the maximum number of people (lessons with 56 people) and with the hours of the windows closed, the required airflow rate was found to be 1500 m^3/h. This value is the value required for the CO_2 concentration not to exceed the 1000 ppm limit. Also, this value is equivalent to the air flow rate provided by the ventilation system in the class when operated at maximum capacity.

- According to the CO_2 concentration estimation curves created by taking into account the total capacity of the class T214 (64 people), the capacity of the ventilation system in the class is not sufficient. This air flow rate was found to be 1750 m^3/h.

The results of the surveys are as follows;

- In the results of the survey conducted for both academic periods, the average of PMV values was found within the range specified in the standards for comfort conditions.

In intervals where the outside temperature average is too low or too high (usually 1.5 months), the HVAC system is programmed for automatic activation in the early hours. In this case, air conditioners in all areas are opened automatically and unnecessary operation continues in unused areas. To reduce energy consumption, it is recommended to use the HVAC system in manual mode and set it to automatic mode only at extreme temperatures. Considering the Izmir weather conditions, a maximum of 2 weeks of operation time is recommended for automatic mode.

The proposed and potential future plans are as follows;

- In this study, the insufficiency of the measured parameters caused many assumptions. Healthier results can be obtained by regularly measuring the airflow rate, user density, and door opening parameters in the environment.
- Since the energy consumption data could not be reached on a class basis, the effects of the measurement results made in the classes on the energy consumption could not be directly examined. Energy consumption data can be measured on a floor and class basis.
- Although the estimated number of people in the class can be reached, the distribution of occupancy on the basis of some parameters is unknown (gender, body mass analysis, etc.). For this reason, detailed analysis could not be made. This information can be recorded regularly from the very beginning of the research process.
- The amount of air flow rate required for the CO_2 concentration to maintain the limit level that complies with the standards can be calculated for classes with different volumes.

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APPENDIX 1 – Sample Course Schedules

Table A1. 1 Course Schedule (T-1B10)

T-1B10 Spring Courses (04.02.19-14.05.19)						T-1B10 Spring Final Exams (20.05.19-31.05.19)											
Hour / Day	Mon	Tues	Wed	Thurs	Fri	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Mon	Tues	Wed	Thurs	Fri
8:30-9:20				44													
9:30-10:20	17	55							45								
10:30-11:20					37								28		35		
11:30-12:20																23	
12:30-13:20					55		42	41	39				41		37		
13:30-14:20	56	35	35													39	
14:30-15:20					35		42	34		42			42				
15:30-16:20				78													
16:30-17:20	61																
17:30-18:20																	

T-1B10 Fall Courses (16.09.19-24.12.19)						T-1B10 Fall Final Exams (02.01.20-15.01.20)													
Hour / Day	Mon	Tues	Wed	Thurs	Fri	Thurs	Fri	Sat	Sun	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Mon	Tues	Wed
8:30-9:20		50																	
9:30-10:20	17		22														32		
10:30-11:20		79			56						44	28		37					
11:30-12:20																			
12:30-13:20		52	23	37							46						35		
13:30-14:20	23																		
14:30-15:20		43	48	54	19												39	36	
15:30-16:20																			
16:30-17:20																			
17:30-18:20																			

Table A1. 2. Course Schedule (T214)

T214 Spring Courses (04.02.19-14.05.19)						T214 Spring Final Exams (20.05.19-31.05.19)											
Hour / Day	Mon	Tues	Wed	Thurs	Fri	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Mon	Tues	Wed	Thurs	Fri
8:30-9:20			37	41									23		14		
9:30-10:20																	
10:30-11:20	24	48		40									29				
11:30-12:20			41														
12:30-13:20				18			29	25	27						23		
13:30-14:20	18	38	41														
14:30-15:20		38		23	56		30	31	29				31		33		
15:30-16:20		41															
16:30-17:20			40														
17:30-18:20								33		35							

T214 Fall Courses (16.09.19-24.12.19)						T214 Fall Final Exams (02.01.20-15.01.20)													
Hour / Day	Mon	Tues	Wed	Thurs	Fri	Thurs	Fri	Sat	Sun	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Mon	Tues	Wed
8:30-9:20			19	37	8					33									
9:30-10:20	22	45																	
10:30-11:20										25	9		31	39			27		
11:30-12:20	22		42	11	28		19												
12:30-13:20		25																	
13:30-14:20	43		43			48				27	26	17	29	23					
14:30-15:20		38		53															
15:30-16:20	34		34			44				33		33							
16:30-17:20																			
17:30-18:20																			

Table A1. 3. Course Schedule (T514)

T514 Spring Courses (04.02.19-14.05.19)						T514 Spring Final Exams (20.05.19-31.05.19)											
Hour / Day	Mon	Tues	Wed	Thurs	Fri	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Mon	Tues	Wed	Thurs	Fri
8:30-9:20			59														
9:30-10:20	12							39								57	
10:30-11:20		54	59	59	35											43	
11:30-12:20																	
12:30-13:20			21				39										
13:30-14:20	57												37				
14:30-15:20		10	16	59	11			16	28	39					39		11
15:30-16:20																	
16:30-17:20																	
17:30-18:20																	

T514 Fall Courses (16.09.19-24.12.19)						T514 Fall Final Exams (02.01.20-15.01.20)													
Hour / Day	Mon	Tues	Wed	Thurs	Fri	Thurs	Fri	Sat	Sun	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Mon	Tues	Wed
8:30-9:20	30			92															
9:30-10:20			60			54						21		16					20
10:30-11:20		54									53								
11:30-12:20			50																
12:30-13:20	36			60						36	6		39						
13:30-14:20												19		24				55	
14:30-15:20		6																	
15:30-16:20																			
16:30-17:20				36															
17:30-18:20																			

Table A1. 4. Course Schedule (Y213)

Y213 Spring Courses (04.02.19-14.05.19)						Y213 Spring Final Exams (20.05.19-31.05.19)											
Hour / Day	Mon	Tues	Wed	Thurs	Fri	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Mon	Tues	Wed	Thurs	Fri
8:30-9:20	38	54	45	37	42												
9:30-10:20																	
10:30-11:20	54		54	54													
11:30-12:20					54								40				
12:30-13:20	49	49	49	17													
13:30-14:20					50												
14:30-15:20	21	37	56	49													
15:30-16:20																	
16:30-17:20		2	7														
17:30-18:20	28													23			

Y213 Fall Courses (16.09.19-24.12.19)						Y213 Fall Final Exams (02.01.20-15.01.20)													
Hour / Day	Mon	Tues	Wed	Thurs	Fri	Thurs	Fri	Sat	Sun	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Mon	Tues	Wed
8:30-9:20	7	46	46		25														
9:30-10:20												9							
10:30-11:20	18	49	49		28														
11:30-12:20																			
12:30-13:20	13	15	9							8									
13:30-14:20					25														
14:30-15:20			49	48															
15:30-16:20																			
16:30-17:20		2	41							30		10		37					
17:30-18:20																			

Table A1. 5. Course Schedule (Y214)

<table>
<tr><td colspan="6">Y214 Spring Courses (04.02.19-14.05.19)</td><td colspan="12">Y214 Spring Final Exams (20.05.19-31.05.19)</td></tr>
<tr><td>Hour / Day</td><td>Mon</td><td>Tues</td><td>Wed</td><td>Thurs</td><td>Fri</td><td>Mon</td><td>Tues</td><td>Wed</td><td>Thurs</td><td>Fri</td><td>Sat</td><td>Sun</td><td>Mon</td><td>Tues</td><td>Wed</td><td>Thurs</td><td>Fri</td></tr>
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<tr><td>9:30-10:20</td><td></td><td>25</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">36</td><td></td><td rowspan="2">29</td><td></td><td></td></tr>
<tr><td>10:30-11:20</td><td rowspan="2">28</td><td rowspan="2">43</td><td rowspan="3">37</td><td>30</td><td>29</td><td></td><td></td><td></td><td rowspan="2">24</td><td></td><td></td><td></td><td rowspan="2">17</td><td></td><td></td></tr>
<tr><td>11:30-12:20</td><td>43</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>12:30-13:20</td><td rowspan="3">50</td><td rowspan="2">9</td><td>28</td><td rowspan="3">60</td><td></td><td rowspan="2">43</td><td></td><td></td><td>30</td><td></td><td></td><td>25</td><td></td><td></td><td></td><td></td></tr>
<tr><td>13:30-14:20</td><td></td><td rowspan="2">12</td><td></td><td></td><td rowspan="2">28</td><td rowspan="2">24</td><td></td><td></td><td rowspan="2">21</td><td></td><td rowspan="2">20</td><td></td><td></td></tr>
<tr><td>14:30-15:20</td><td rowspan="2">29</td><td rowspan="3">46</td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">29</td><td></td><td></td></tr>
<tr><td>15:30-16:20</td><td></td><td></td><td></td><td></td><td rowspan="2">29</td><td></td><td rowspan="2">29</td><td>25</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>16:30-17:20</td><td rowspan="2">12</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>17:30-18:20</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<table>
<tr><td colspan="6">Y214 Fall Courses (16.09.19-24.12.19)</td><td colspan="14">Y214 Fall Final Exams (02.01.20-15.01.20)</td></tr>
<tr><td>Hour / Day</td><td>Mon</td><td>Tues</td><td>Wed</td><td>Thurs</td><td>Fri</td><td>Thurs</td><td>Fri</td><td>Sat</td><td>Sun</td><td>Mon</td><td>Tues</td><td>Wed</td><td>Thurs</td><td>Fri</td><td>Sat</td><td>Sun</td><td>Mon</td><td>Tues</td><td>Wed</td></tr>
<tr><td>8:30-9:20</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>11:30-12:20</td><td>40</td><td></td><td>40</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>12:30-13:20</td><td></td><td rowspan="2">60</td><td rowspan="2">11</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>13:30-14:20</td><td></td><td>67</td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">35</td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">19</td><td></td><td></td></tr>
<tr><td>14:30-15:20</td><td></td><td rowspan="2">72</td><td rowspan="2">51</td><td rowspan="3">66</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>15:30-16:20</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>16:30-17:20</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>17:30-18:20</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

APPENDIX 2 – Survey Questions

1.Bulunduğunuz Mahal'in Numarası?

2.Cinsiyetiniz?

- Kadın
- Erkek

3.Yaşınız?

- 18-20
- 21-23
- 24-26
- 27-30
- 31-35
- 36-40
- 41-50
- >50

4.Boyunuz?

- <1.50 m
- 1.50-1.60 m
- 1.60-1.70 m
- 1.70-1.80 m
- 1.80-1.90 m
- 1.90-2.00 m
- 2.00 m

5.Kilonuz?

- <50 kg
- 50-60 kg
- 60-70 kg
- 70-80kg
- 80-90kg
- 90-100 kg
- >100kg

6.Mahaldeki şu anki konumunuz?

- Pencere yakını
- Dış duvar yakını
- Kapı yakını
- Diğer

7.Şu anki giyim durumunuza uyan giysileri seçiniz.

- Uzun kollu gömlek/tişört
- Kısa kollu gömlek/tişört
- Kolsuz gömlek/tişört
- Sweatshirt
- Kazak
- Yelek/Süeter
- Ceket/Hırka
- Kaban
- Kısa Etek/Elbise
- Uzun Etek/Elbise
- Şort
- Kapri
- Kot Pantolon
- Kalın Kumaş Pantolon
- İnce Kumaş Pantolon
- Eşofman
- Tayt
- Atlet/Fanila
- İnce Çorap
- Kalın Çorap
- Bot/Çizme
- Ayakkabı/Spor Ayakkabı
- Sandalet/Terlik

7.GENELDE iç hava sıcaklığı tercih/beklenti aralığınız nedir?

	18-20 ℃ (Soğuk)	21-23 ℃ (Normal)	24-26 ℃ (Sıcak)
Kış	☐	☐	☐
Yaz	☐	☐	☐

8.Mahaldeki ŞU ANKİ iç hava sıcaklığı hakkındaki görüşünüz? *

- çok sıcak
- sıcak
- biraz sıcak
- normal
- biraz soğuk
- soğuk
- çok soğuk

9.Mahalde varsa hissettiğiniz olumsuz konfor koşullarının genel zamanını ve tipini nasıl tanımlarsınız?

	Çok Soğuk	Çok Sıcak
Sabah (8.30-10.30)	☐	☐
Öğle (10.30-14.30)	☐	☐
Öğleden sonra (14.30-18.30)	☐	☐
Akşam (18.30-21.30)	☐	☐

10.Mahaldeki ŞU ANKİ iç hava kalitesi hakkındaki görüşünüz?

- Konforlu/Normal
- Oksijen seviyesi düşük
- Nemli
- Kuru

11.Pencerelerin açılıp açılmaması üzerine görüşünüz nedir? *

- Psikolojik Rahatlık için açmıyorum
- Psikolojik Rahatlık için açıyorum
- Temiz hava ihtiyacı ile açıyorum
- Çok Soğuk olduğu için açmıyorum
- Hava akımı olduğu için açmıyorum

12.Anketin yapıldığı andaki mahaldeki kişi sayısı kaçtır?

____

13.Isıl konfor koşulları hakkında iletmek istediğiniz diğer görüş ve önerileriniz?

____

____

APPENDIX 3 – GRAPHS OF CLASSES

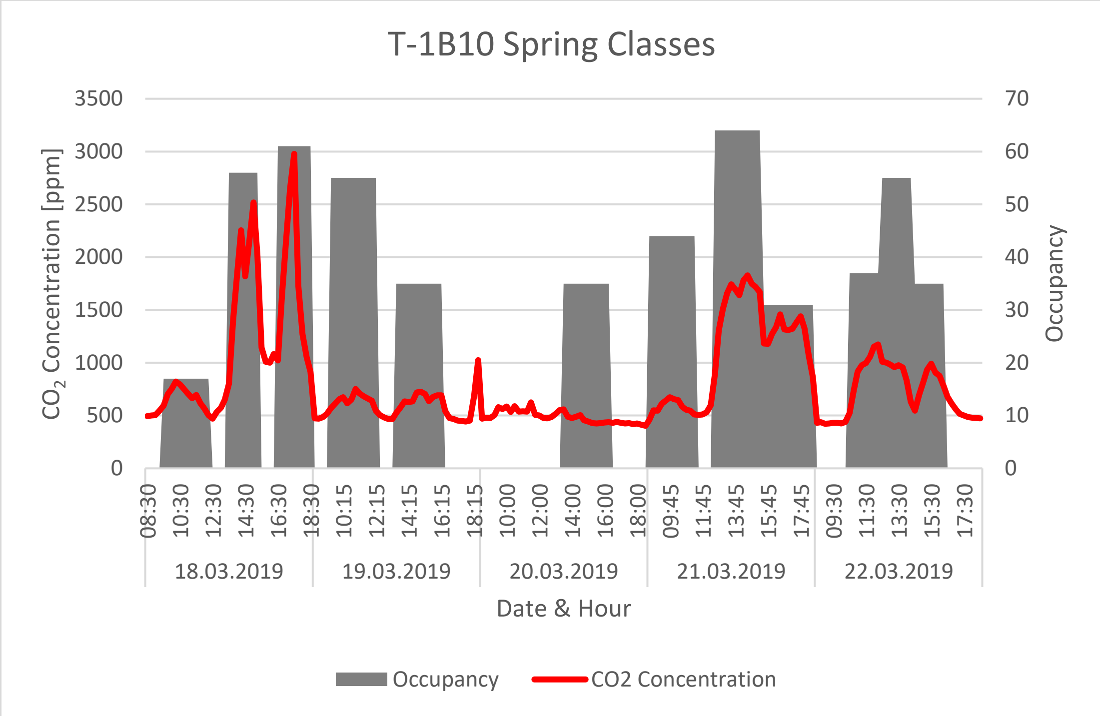

Figure A3. 1. CO_2 Concentration and Occupancy in T-1B10 According to 6th Week of the Spring Term

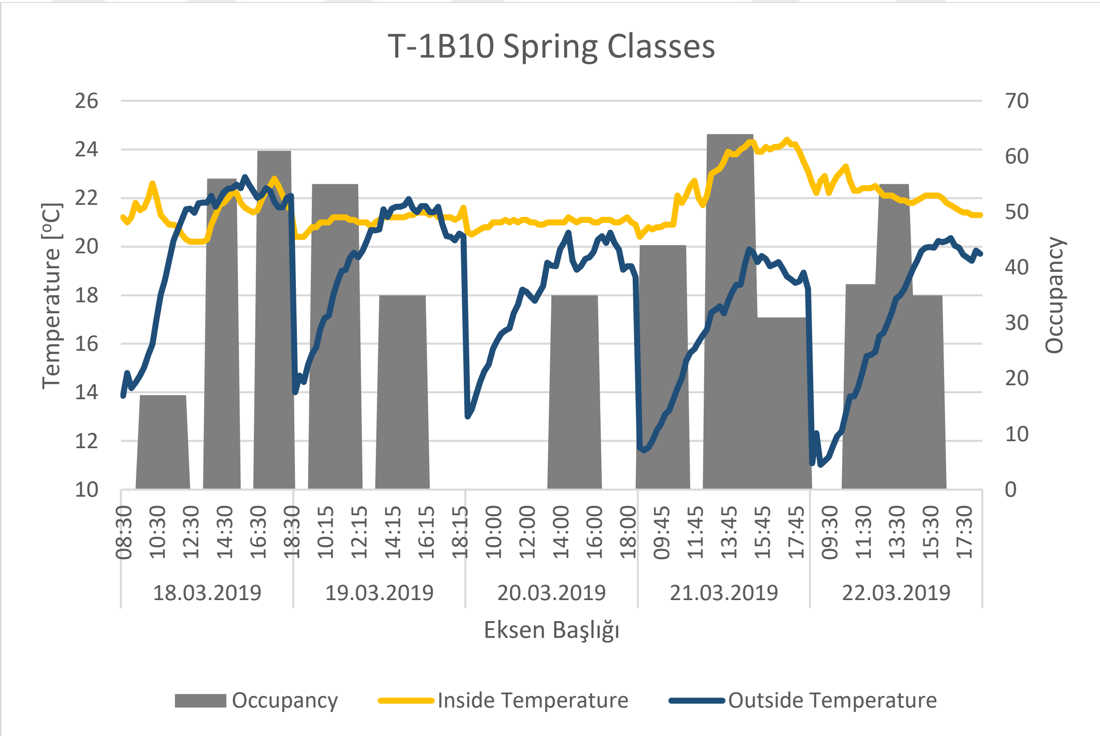

Figure A3. 2. Temperature and Occupancy in T-1B10 According to 6th Week of the Spring Term

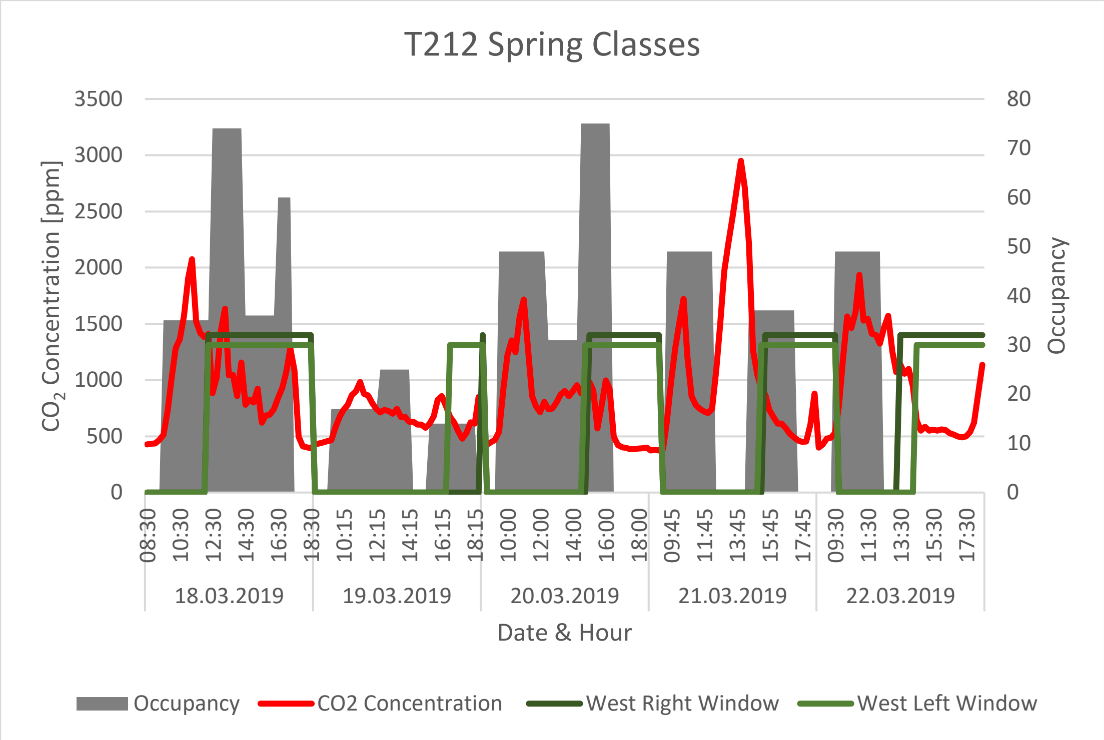

Figure A3. 3. CO_2 Concentration and Occupancy in T212 According to 6th Week of the Spring Term

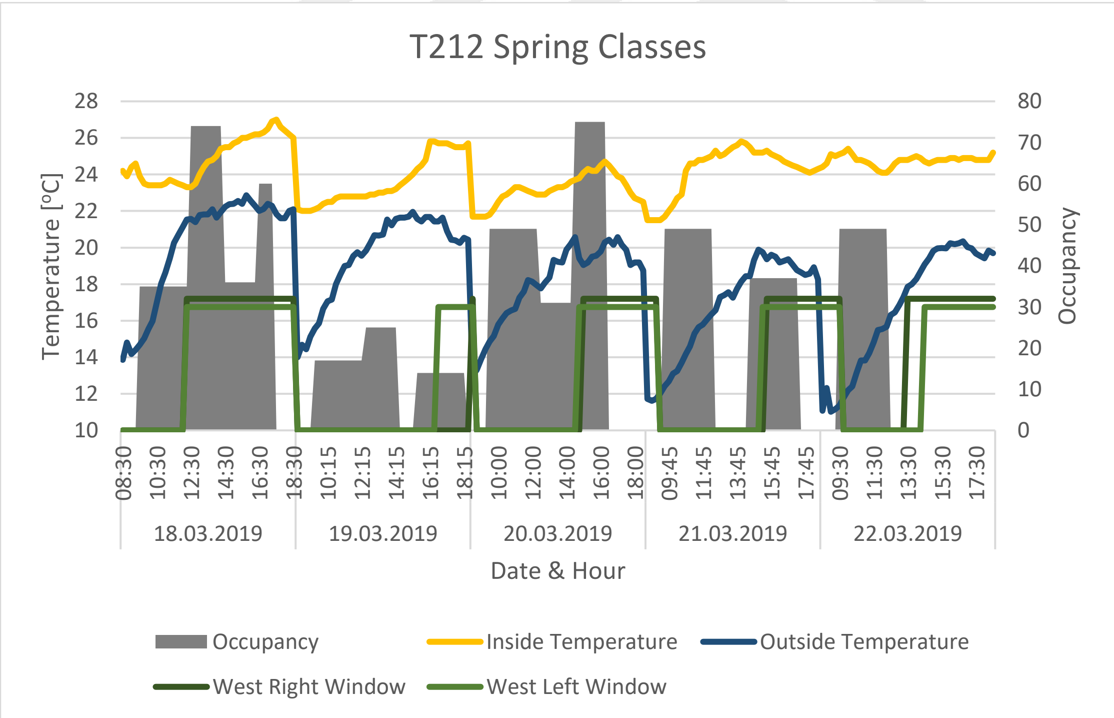

Figure A3. 4. Temperature and Occupancy in T212 According to 6th Week of the Spring Term

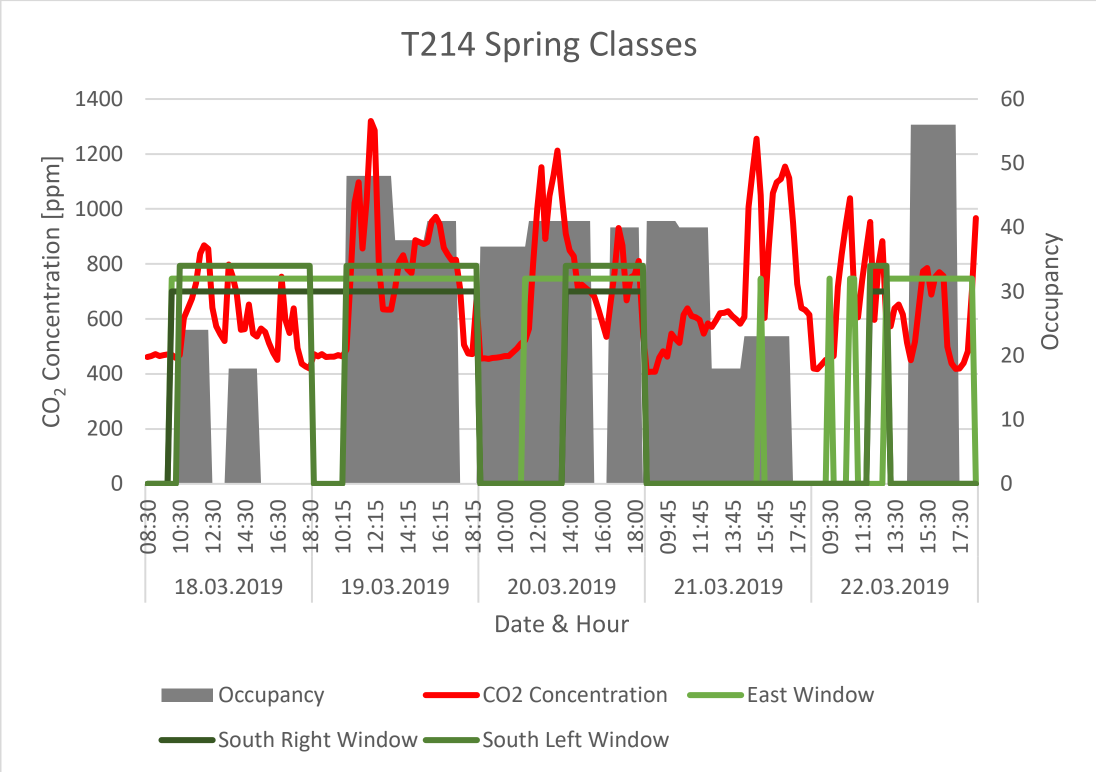

Figure A3. 5. CO_2 Concentration and Occupancy in T214 According to 6th Week of the Spring Term

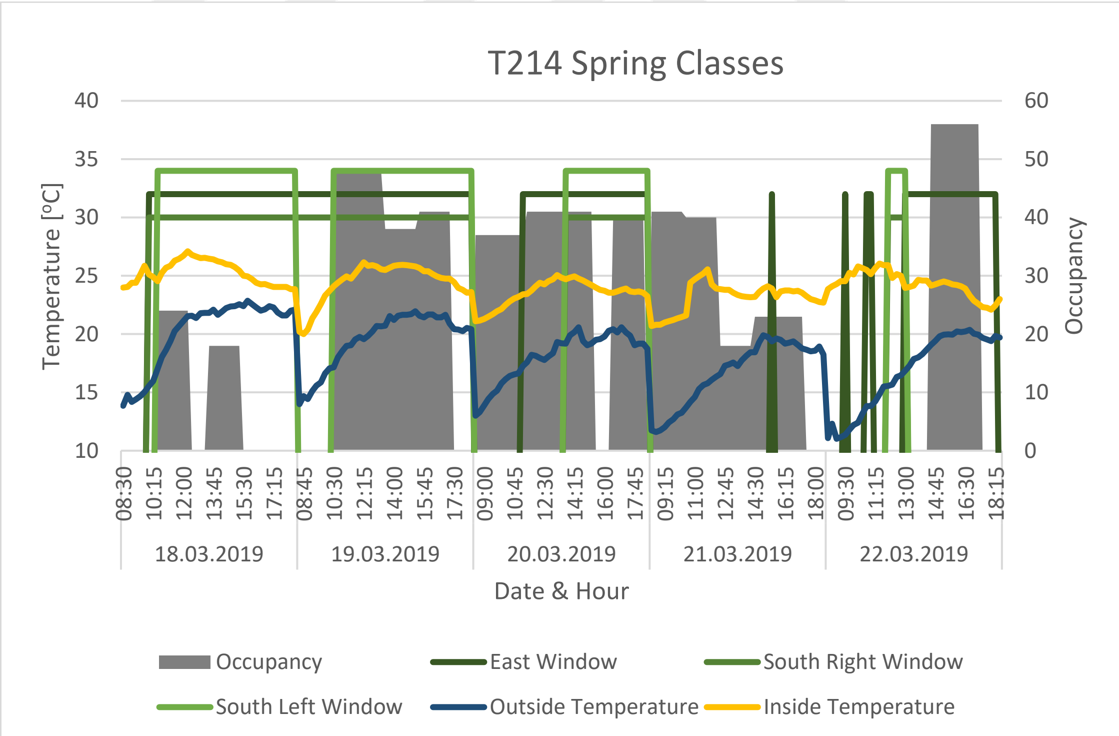

Figure A3. 6. Temperature and Occupancy in T214 According to 6th Week of the Spring Term

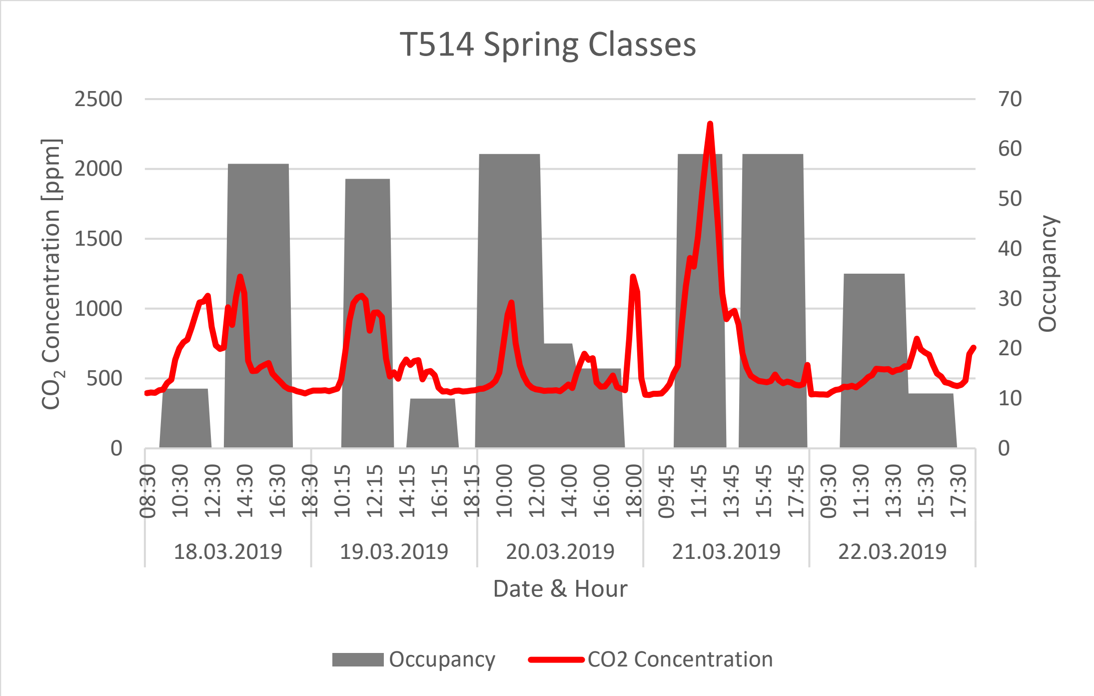

Figure A3. 7. CO_2 Concentration and Occupancy in T514 According to 6th Week of the Spring Term

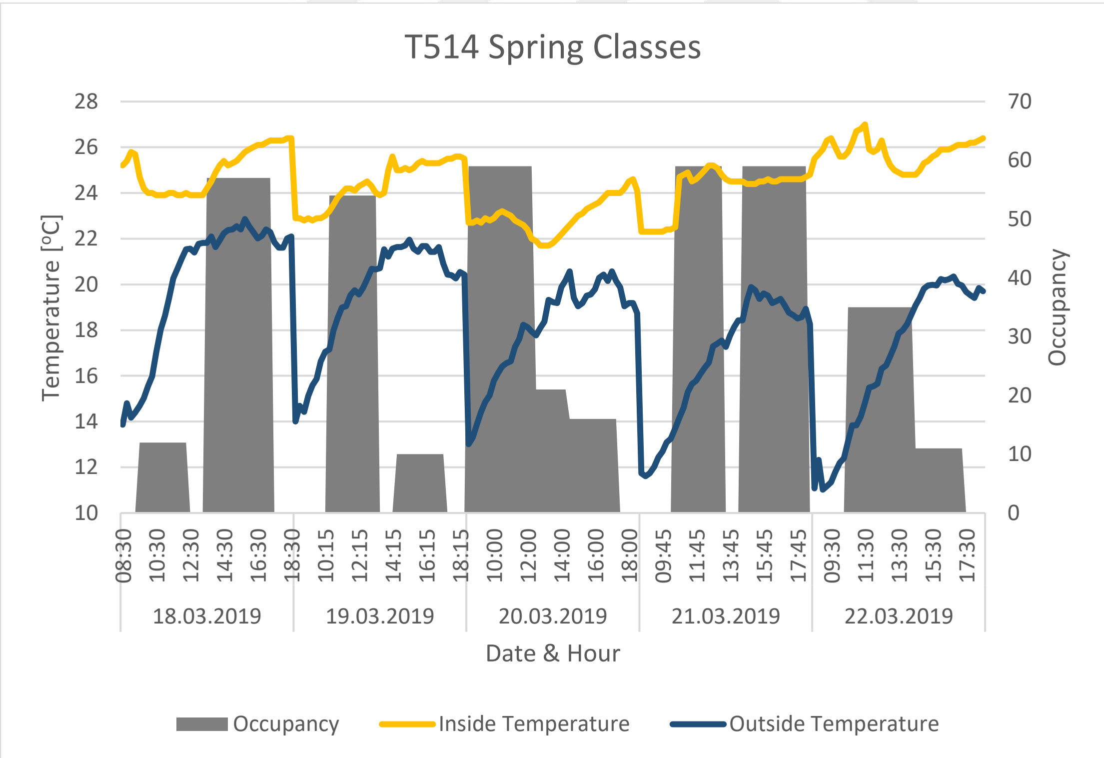

Figure A3. 8. Temperature and Occupancy in T514 According to 6th Week of the Spring Term

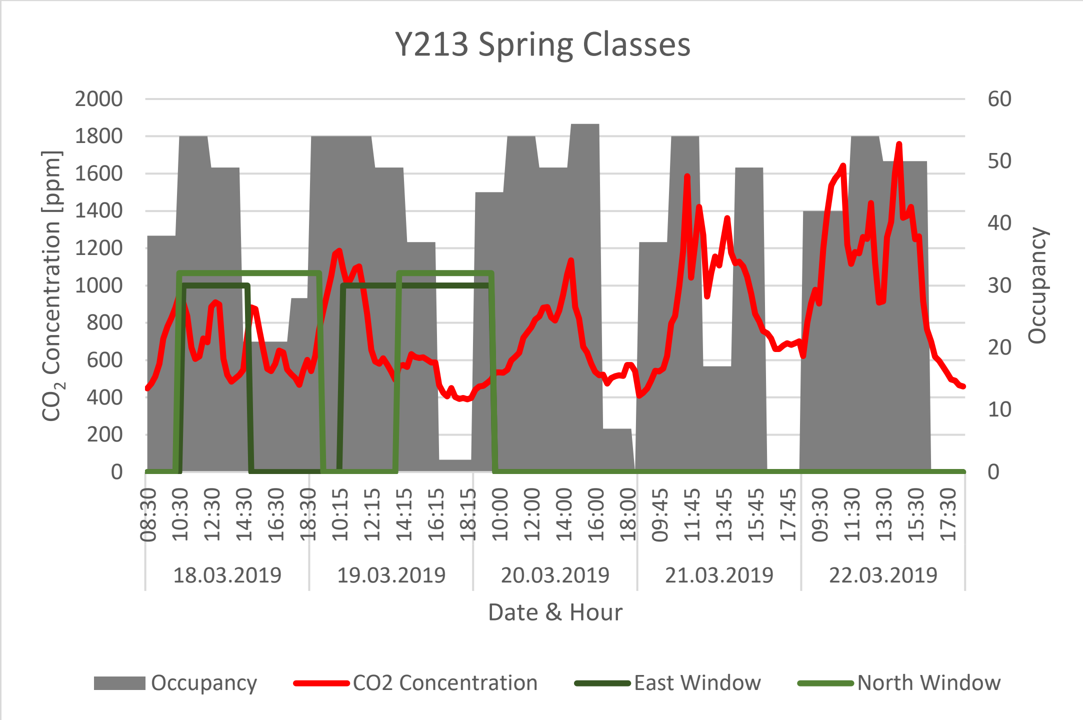

Figure A3. 9. CO_2 Concentration and Occupancy in Y213 According to 6th Week of the Spring Term

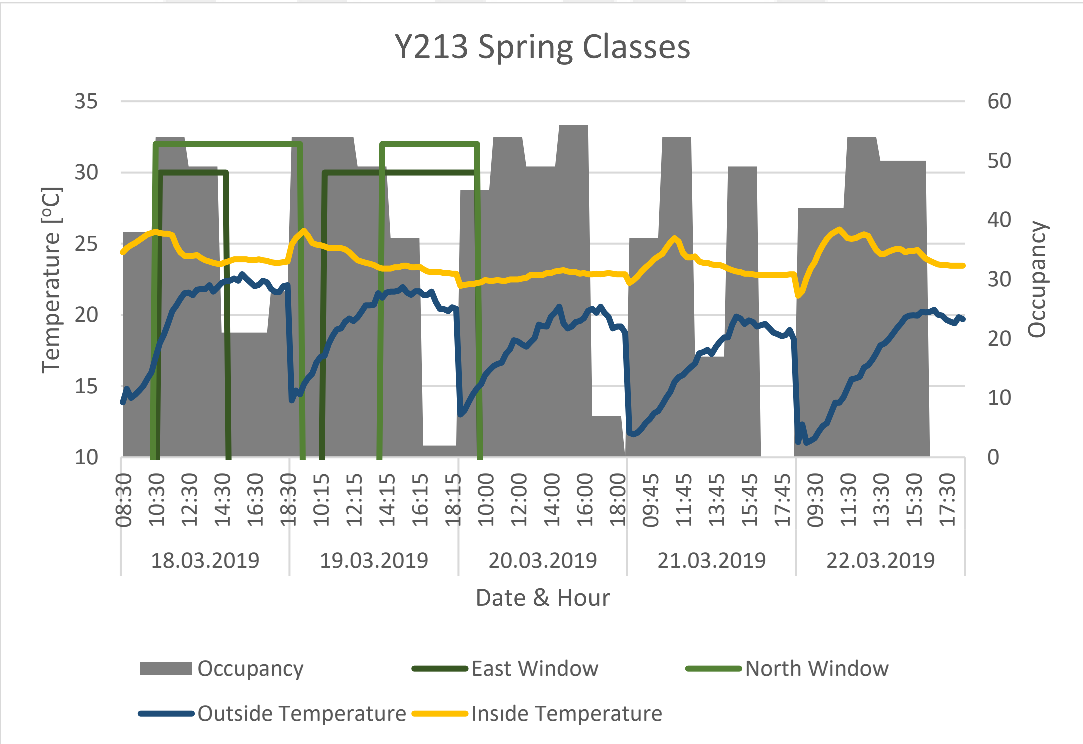

Figure A3. 10. Temperature and Occupancy in Y213 According to 6th Week of the Spring Term

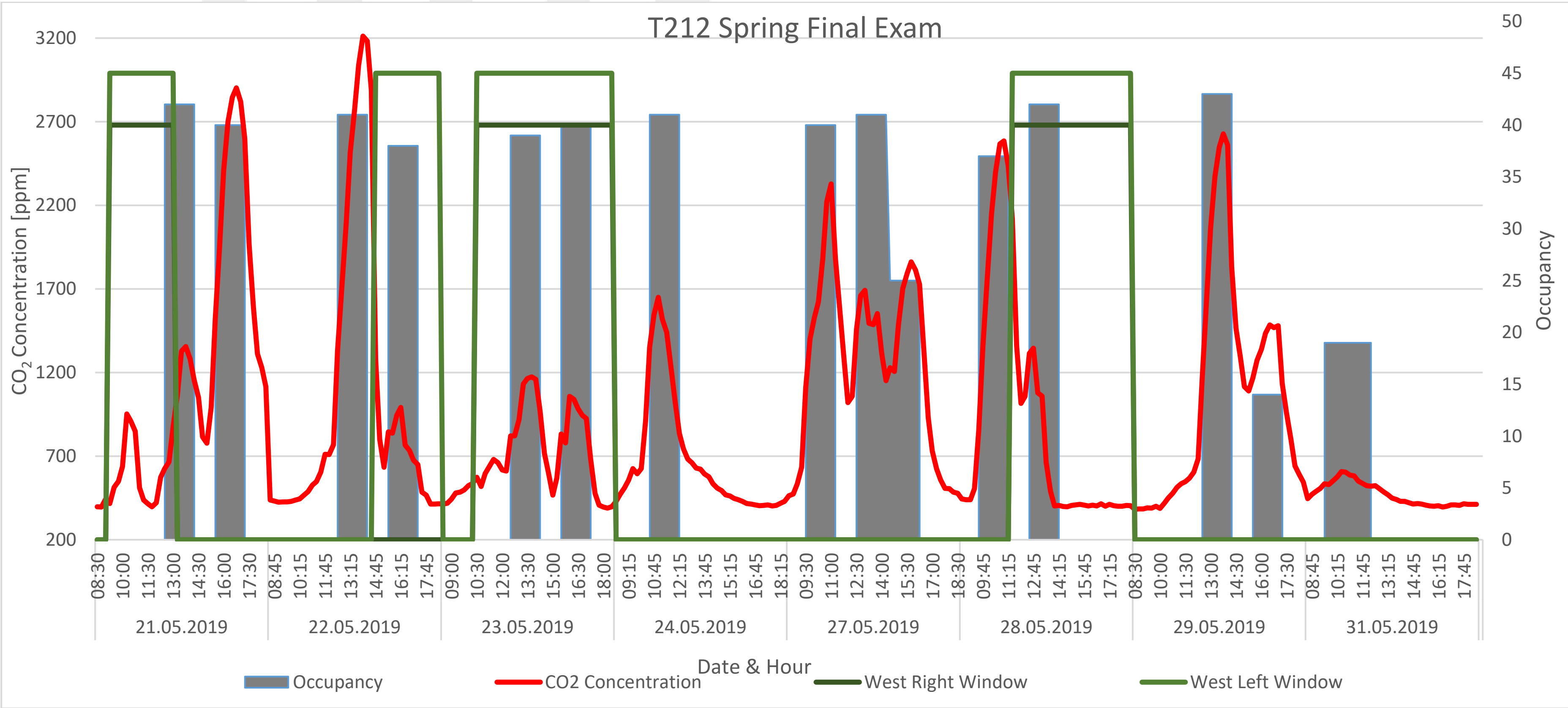

Figure A3. 11. CO_2 Concentration and Occupancy in T212 for Spring Final Exam

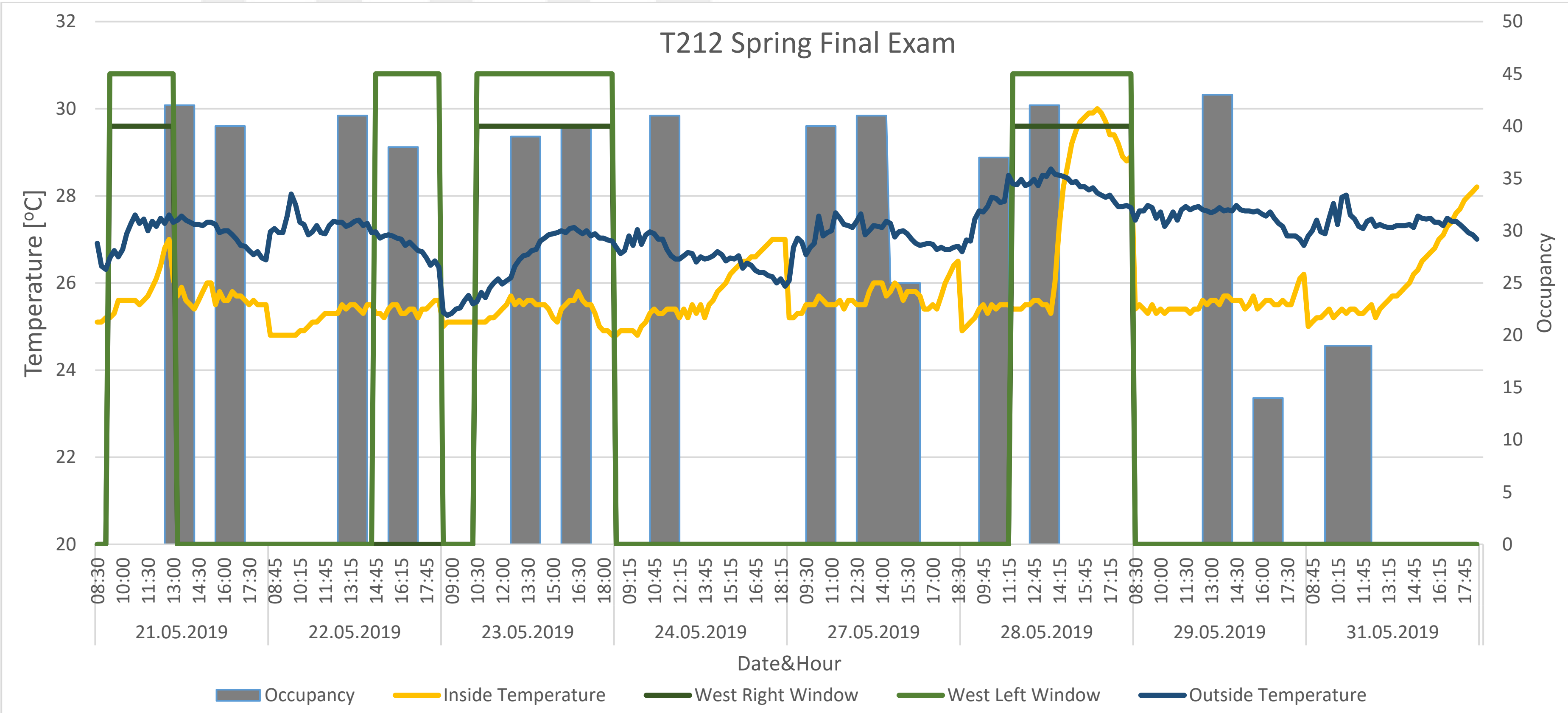

Figure A3. 12. Temperature and Occupancy in T212 for Spring Final Exam Period

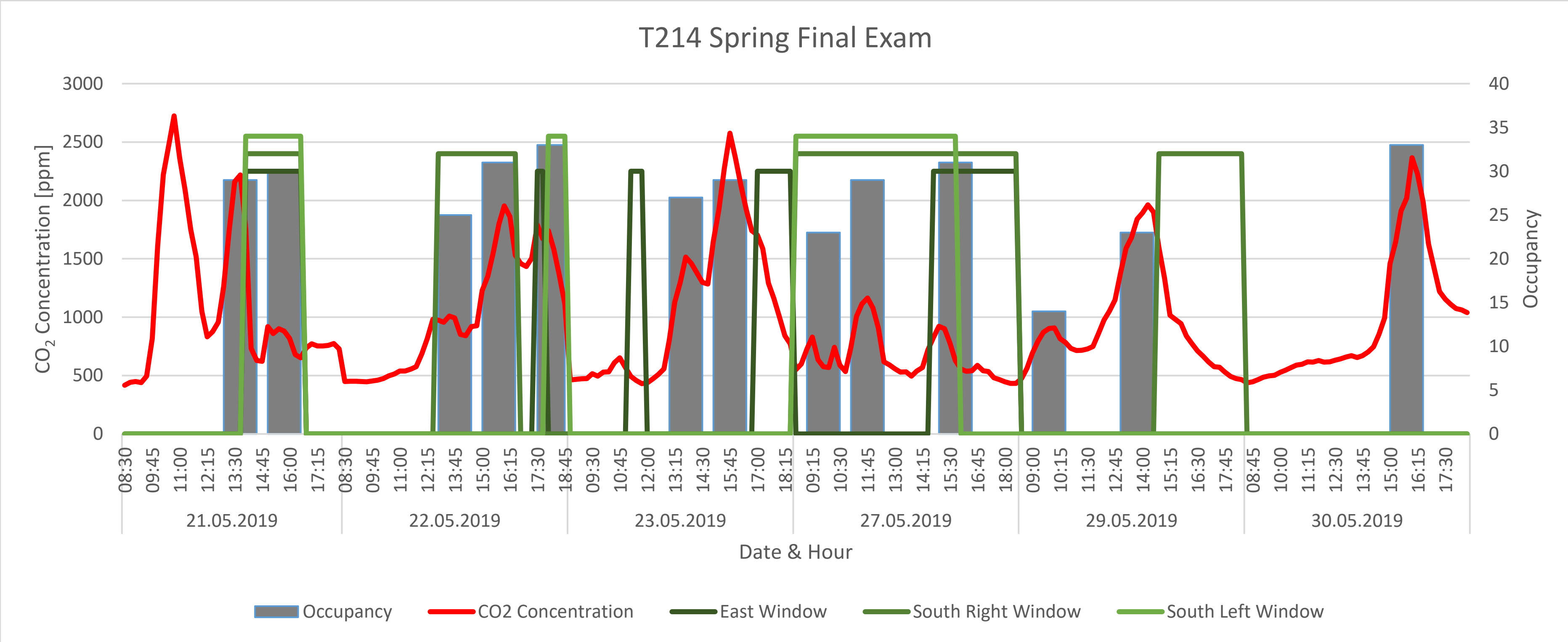

Figure A3. 13. CO_2 Concentration and Occupancy in T214 for Spring Final Exam

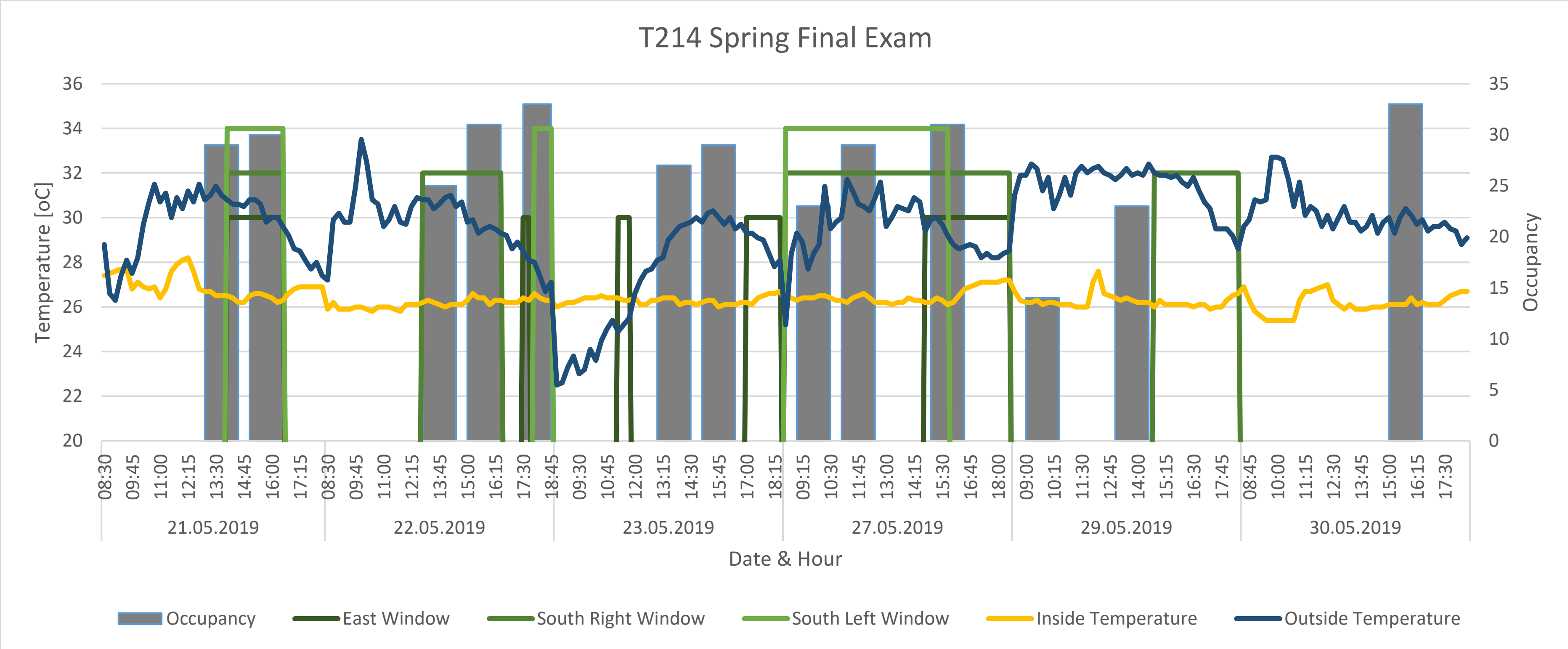

Figure A3. 14. Temperature and Occupancy in T214 for Spring Final Exam Period

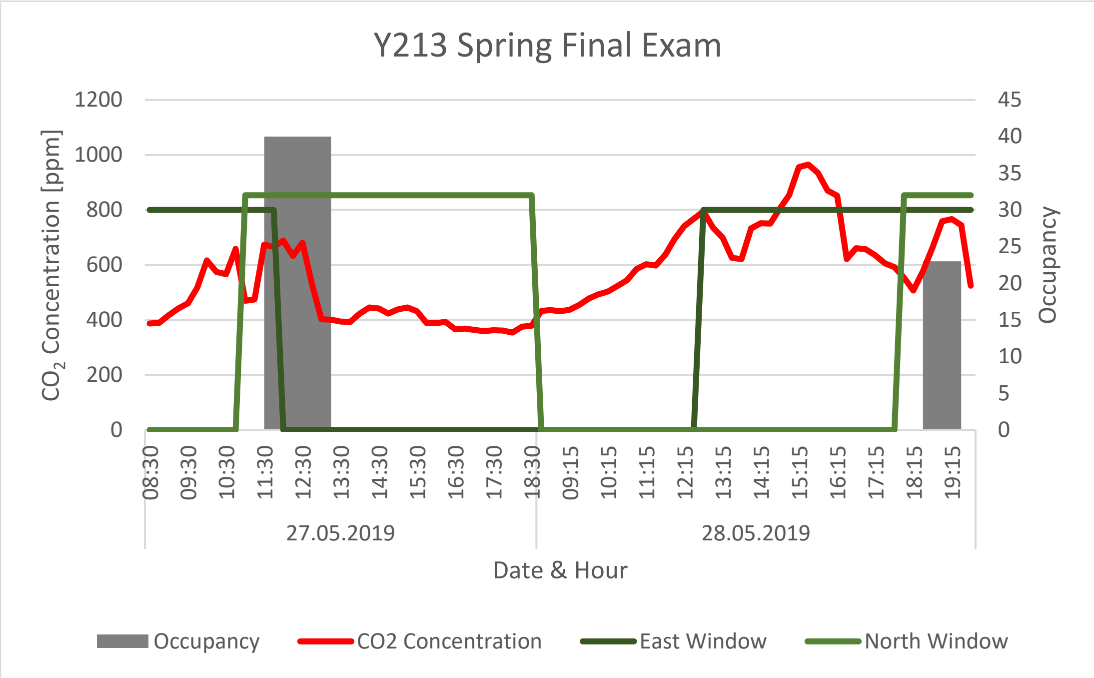

Figure A3. 15. CO_2 Concentration and Occupancy in T212 for Spring Final Exam

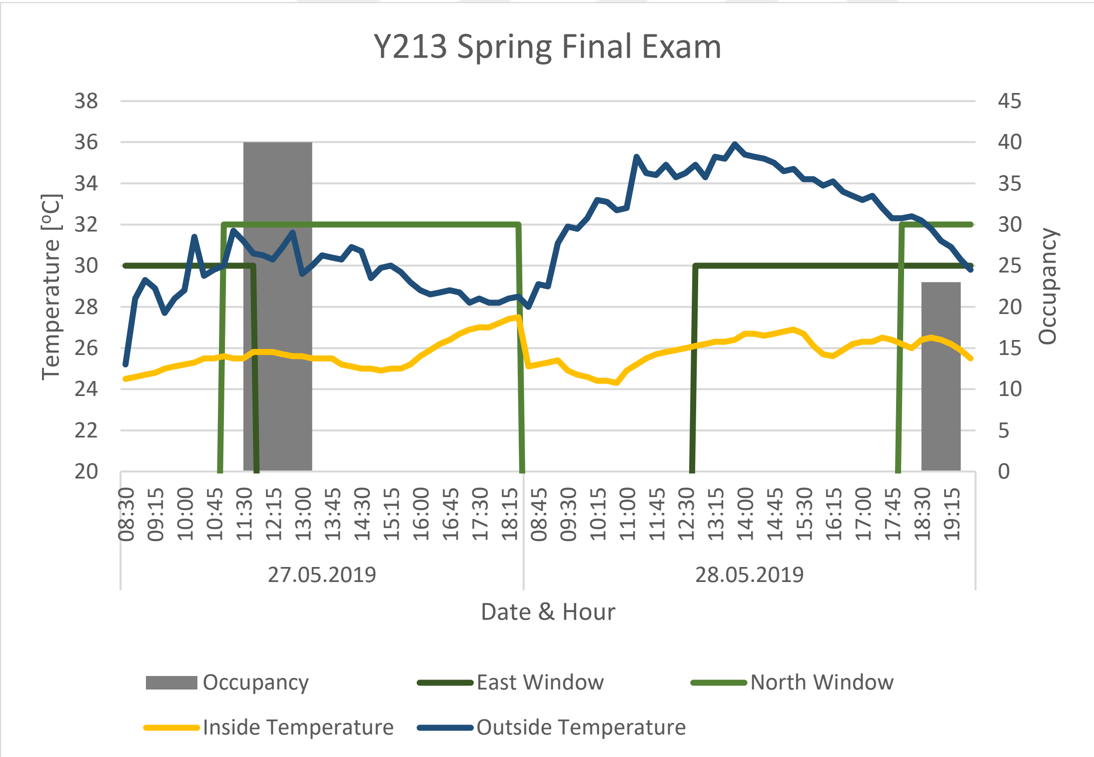

Figure A3. 16. Temperature and Occupancy in Y213 for Spring Final Exam Period

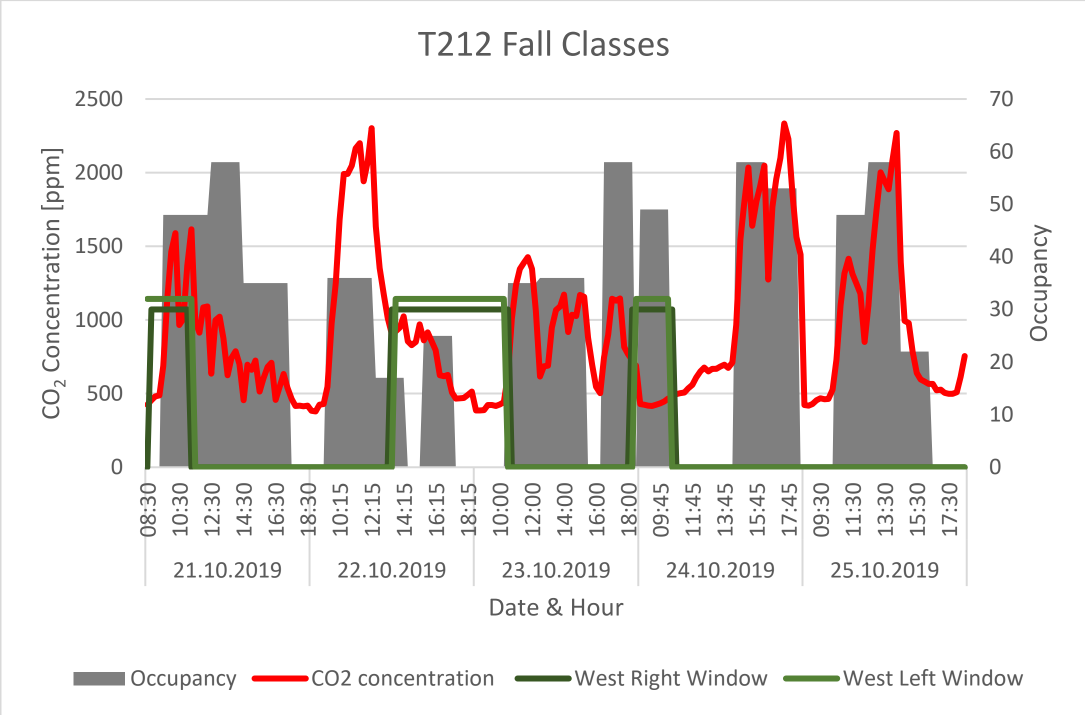

Figure A3. 17. CO_2 Concentration and Occupancy in T212 According to 6th Week of the Fall Term

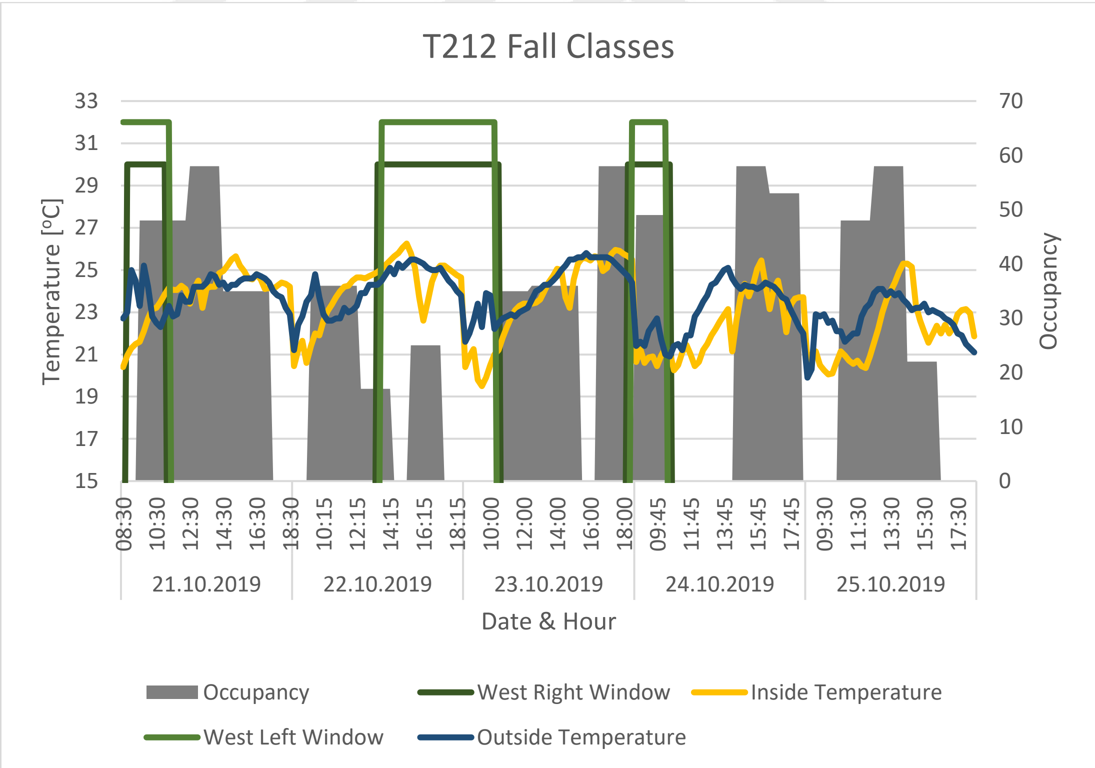

Figure A3. 18. Temperature and Occupancy in T212 According to 6th Week of the Fall Term

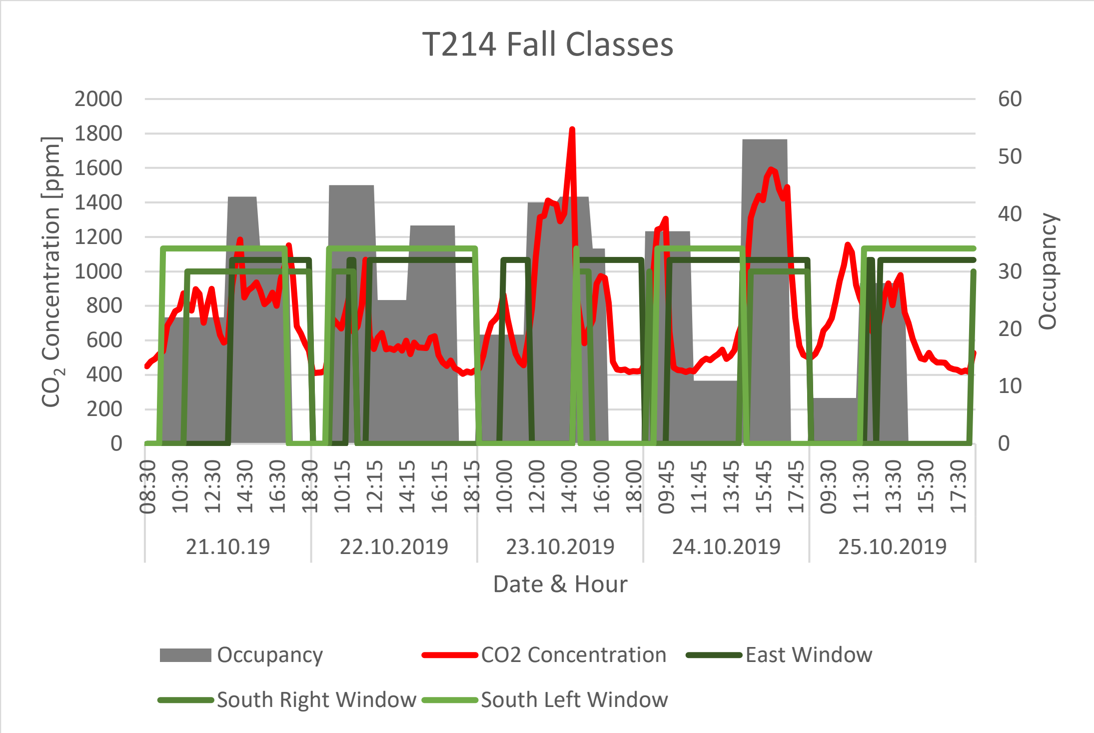

Figure A3. 19. CO_2 Concentration and Occupancy in T214 According to 6th Week of the Fall Term

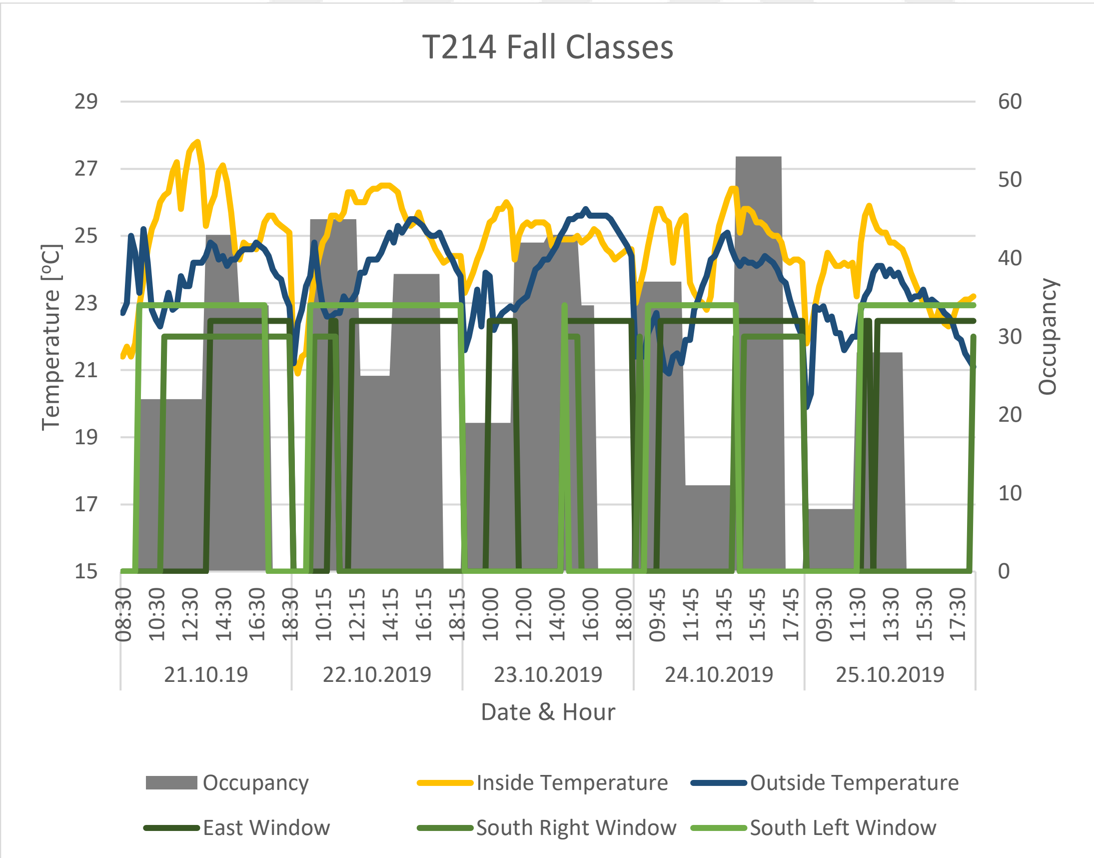

Figure A3. 20. Temperature and Occupancy in T214 According to 6th Week of the Fall Term

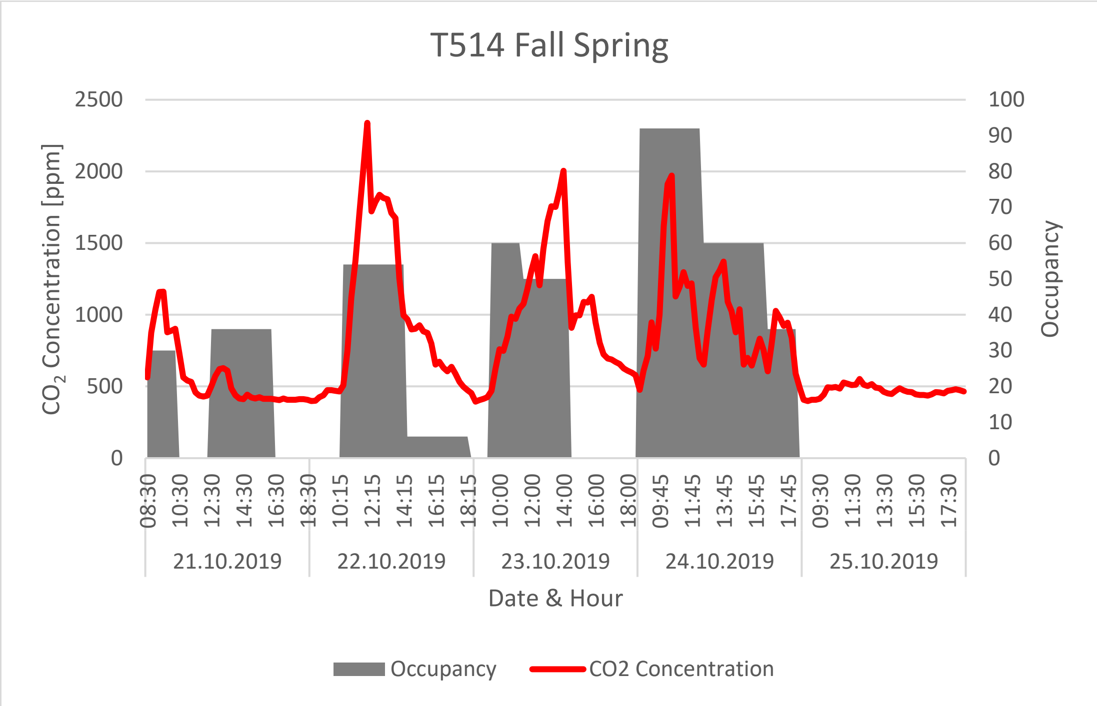

Figure A3. 21. CO_2 Concentration and Occupancy in T514 According to 6th Week of the Fall Term

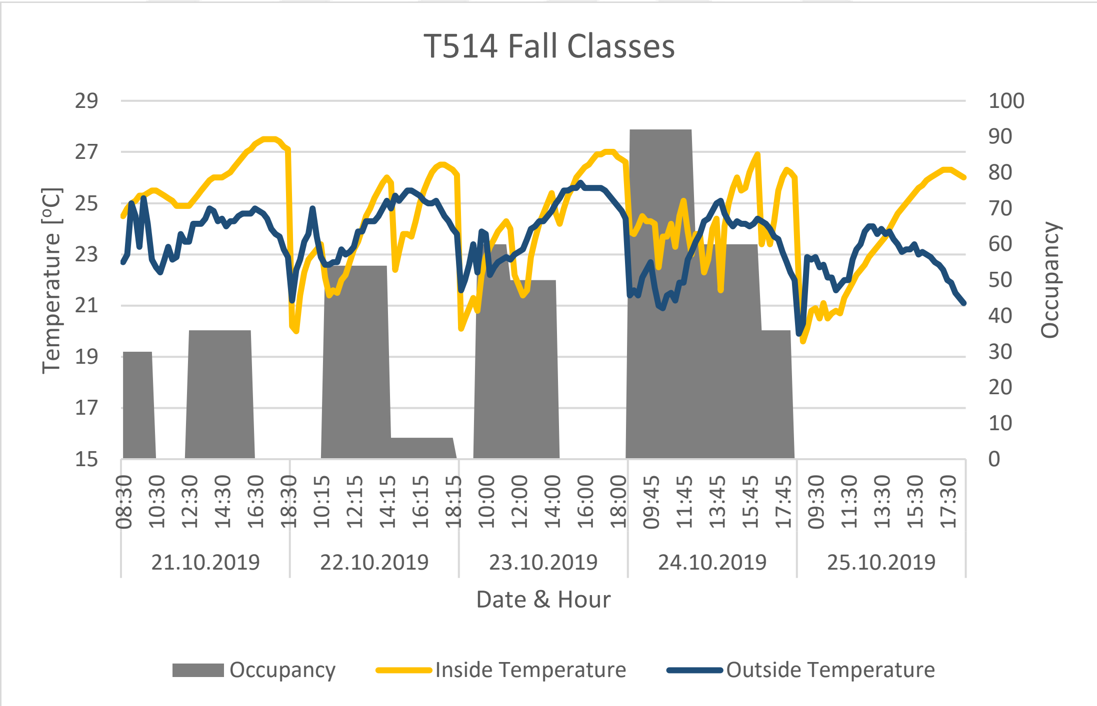

Figure A3. 22. Temperature and Occupancy in T514 According to 6th Week of the Fall Term

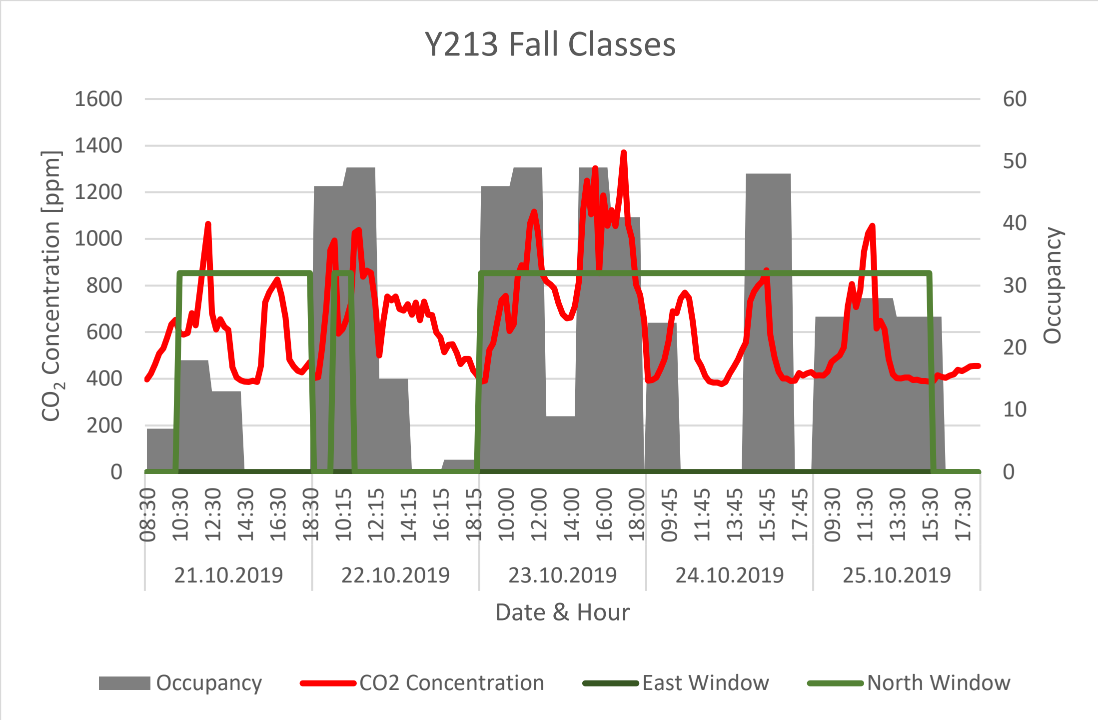

Figure A3. 23. CO_2 Concentration and Occupancy in T212 According to 6th Week of the Fall Term

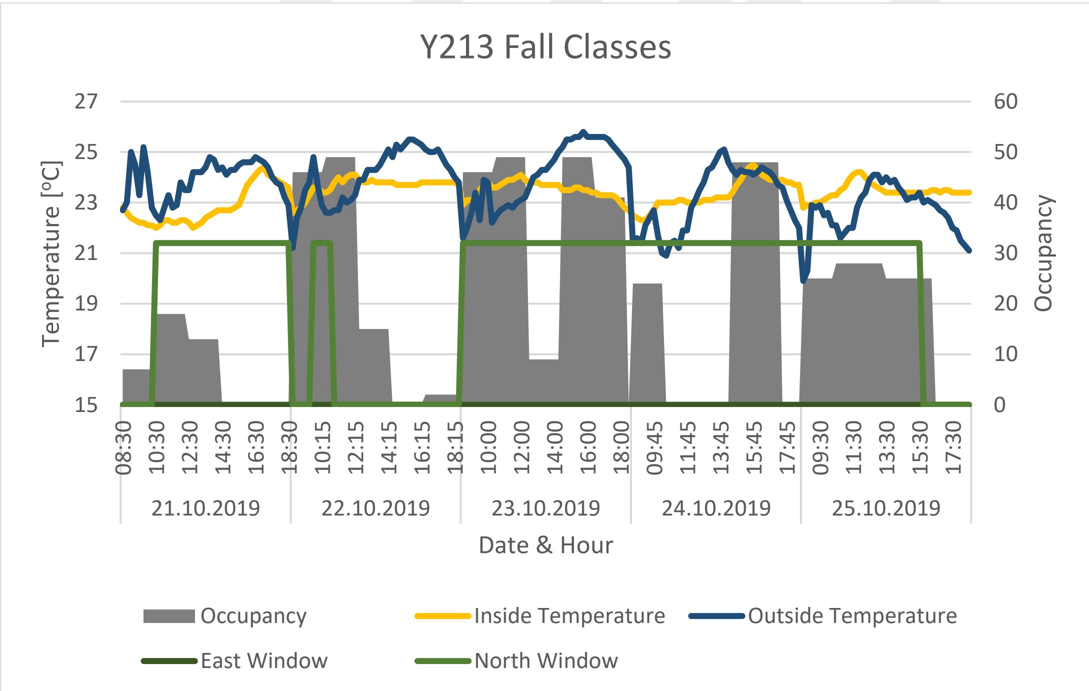

Figure A3. 24. Temperature and Occupancy in Y213 According to 6th Week of the Fall Term

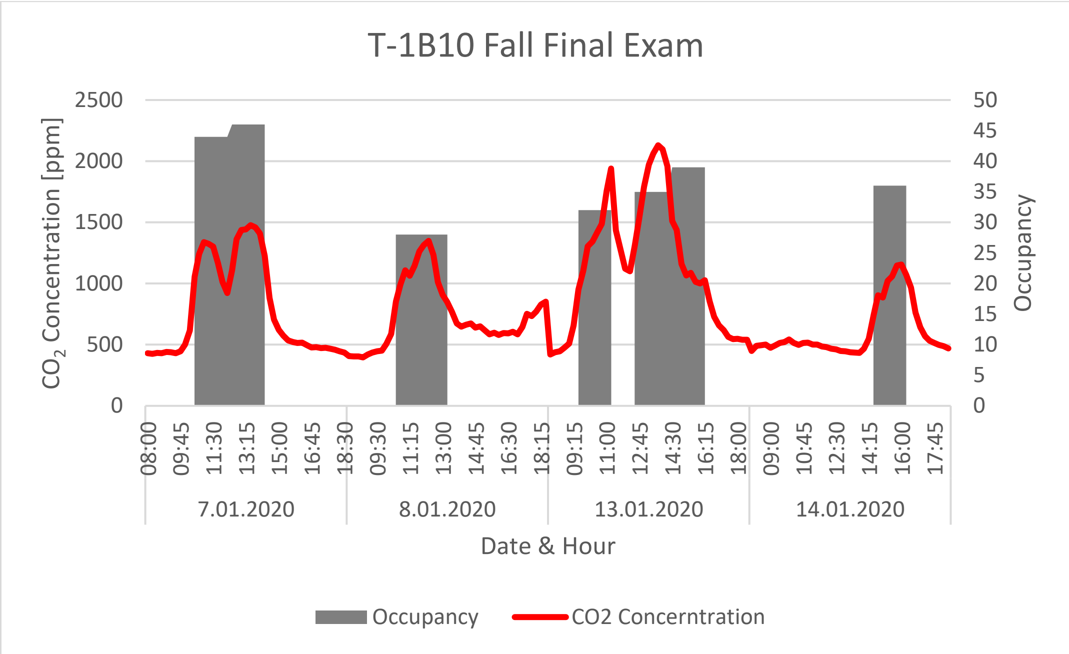

Figure A3. 25. CO_2 Concentration and Occupancy in T-1B10 for Fall Final Exam

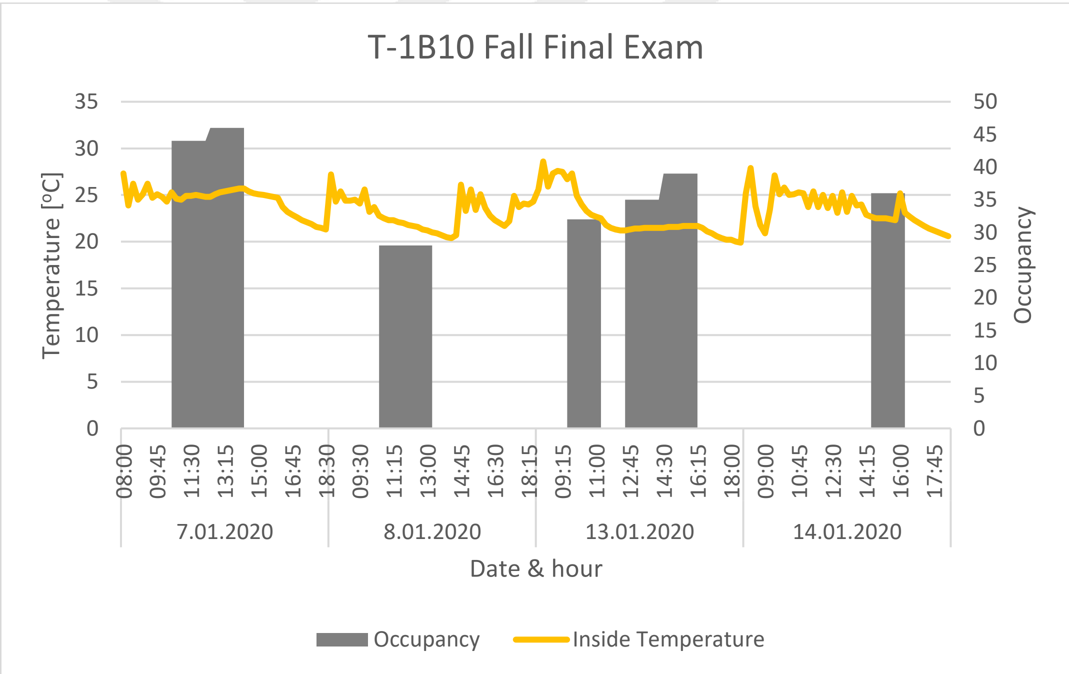

Figure A3. 26. Temperature and Occupancy in T-1B10 for Fall Final Exam Period

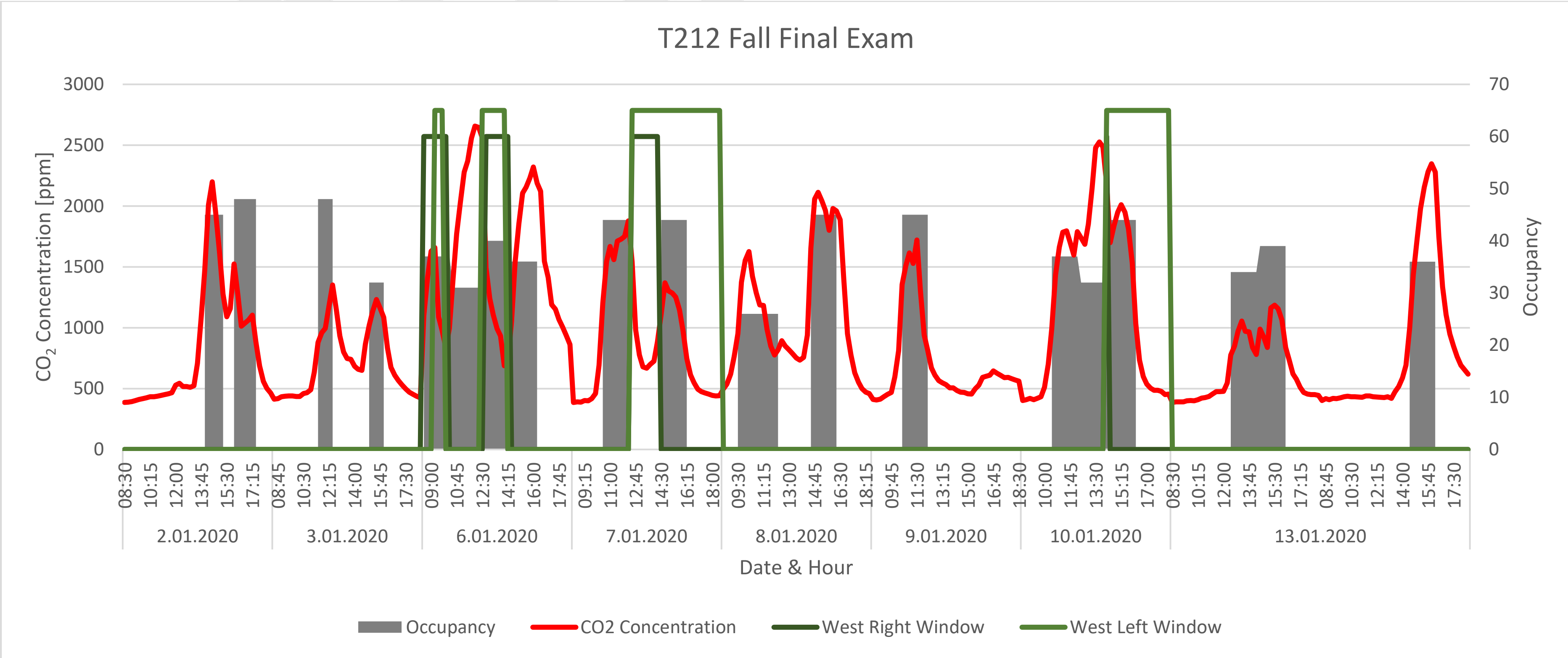

Figure A3. 27. CO_2 Concentration and Occupancy in T212 for Fall Final Exam

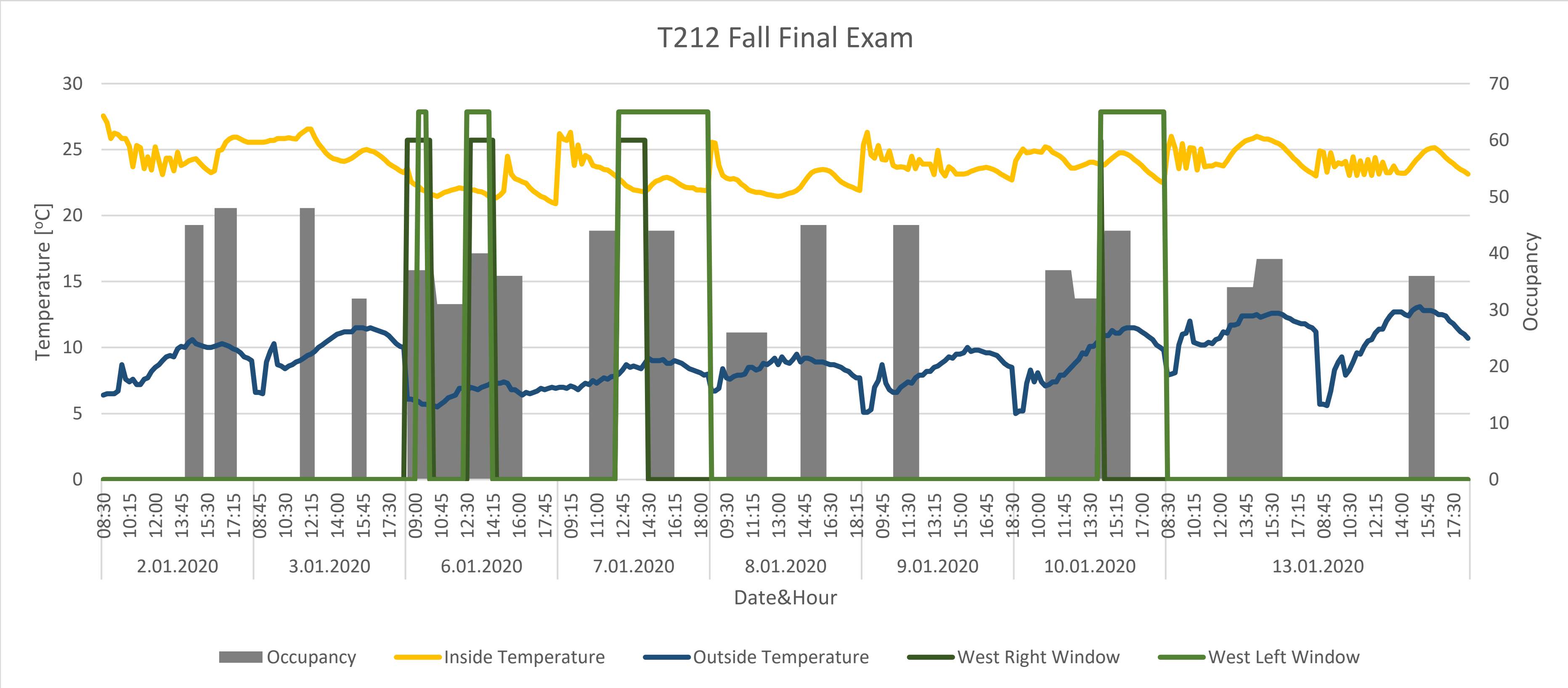

Figure A3. 28. Temperature and Occupancy in T212 for Fall Final Exam Period

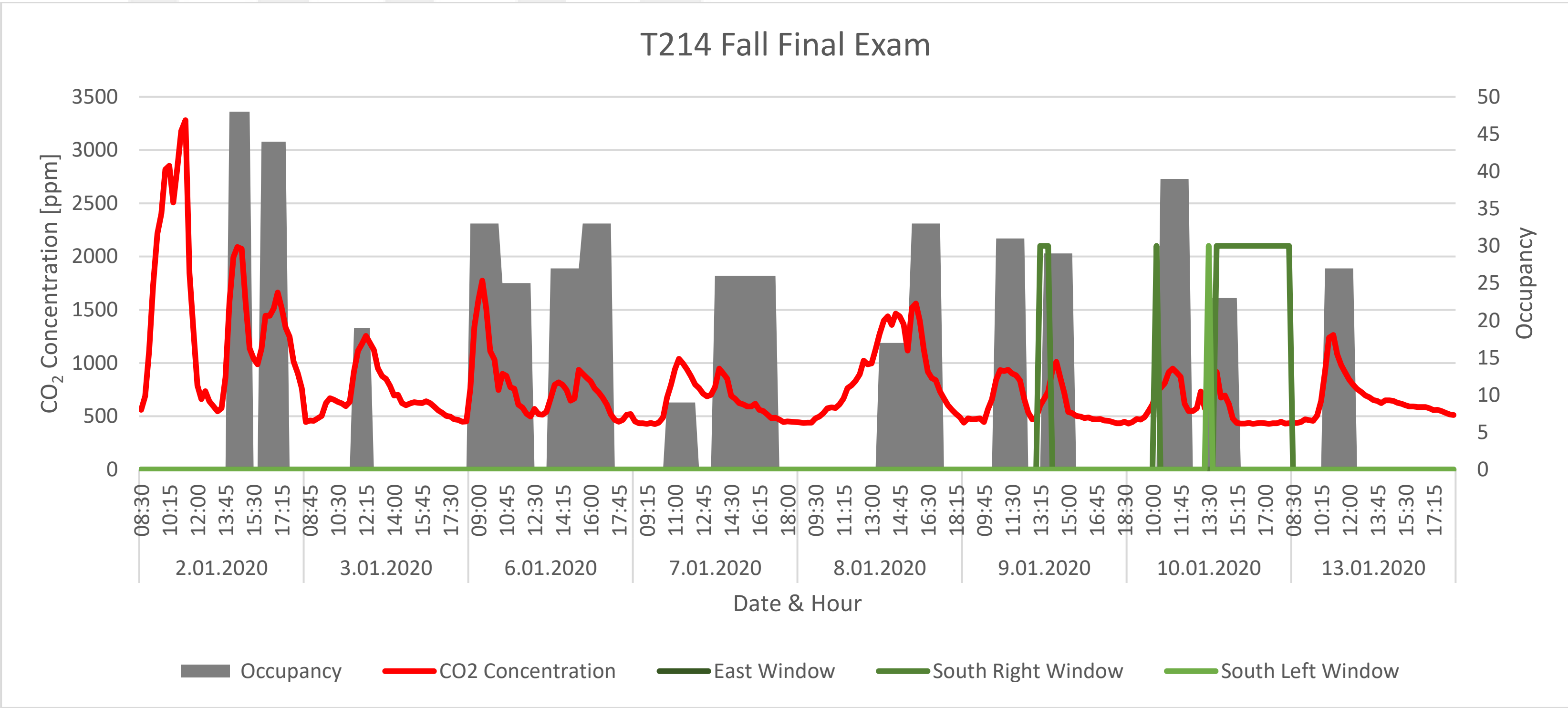

Figure A3. 29. CO_2 Concentration and Occupancy in T214 for Fall Final Exam

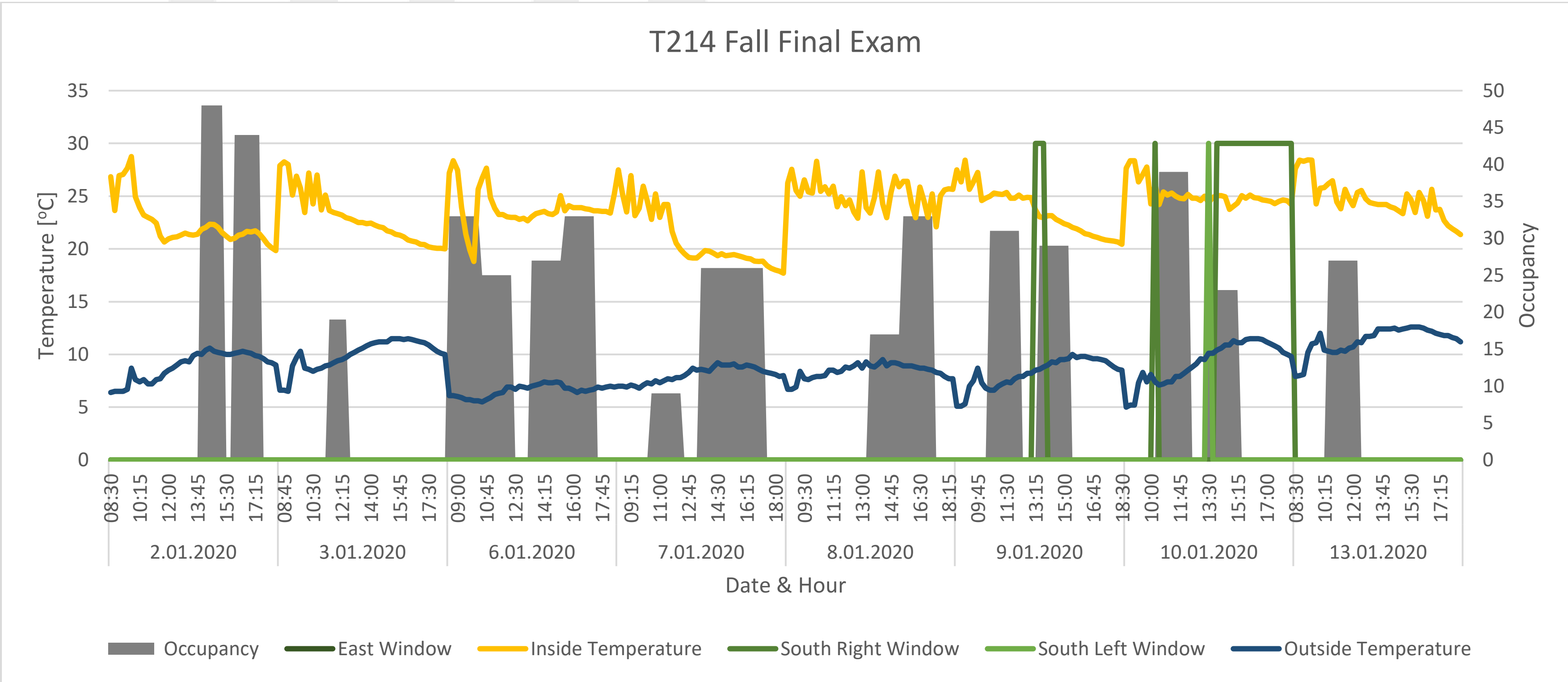

Figure A3. 30. Temperature and Occupancy in T214 for Fall Final Exam Period

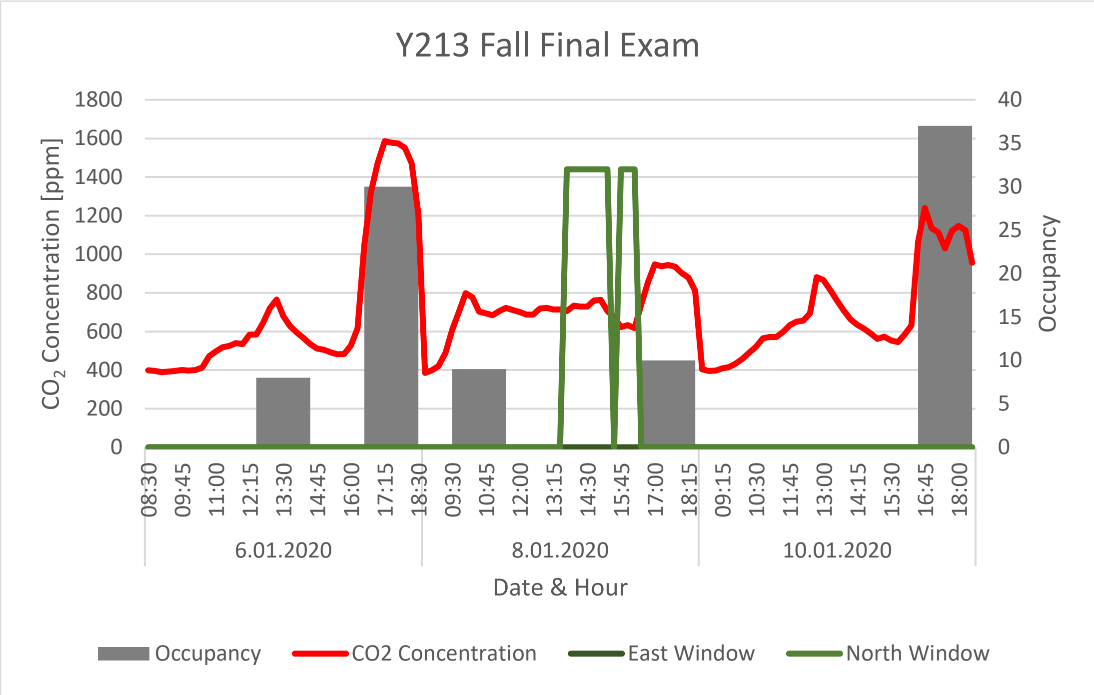

Figure A3. 31. CO_2 Concentration and Occupancy in Y213 for Fall Final Exam

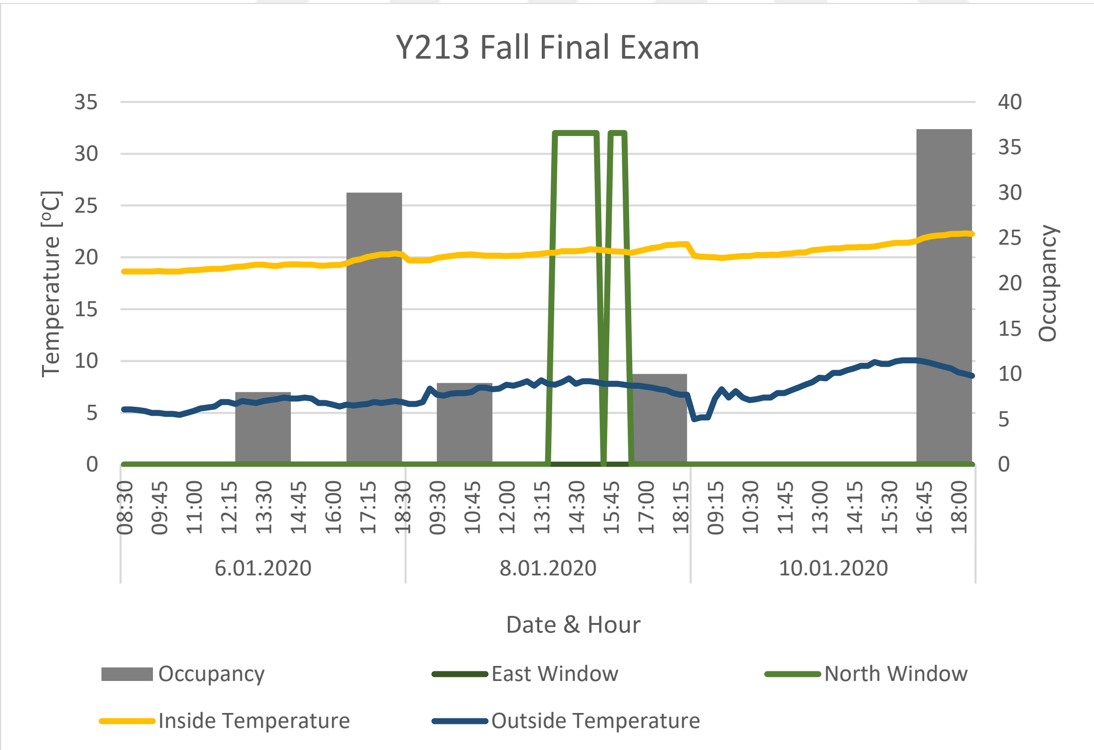

Figure A3. 32. Temperature and Occupancy in Y213 for Fall Final Exam Period