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The Effect of Changing Ventilation Conditions after COVID-19 on Thermal Loads in Naturally Ventilated Higher Education Classrooms

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Abstract

It is difficult to control the recommended ventilation rates for infection control during the COVID-19 preriod by natural ventilation. While insufficient ventilation increases the risk of infection, excessive ventilation can cause problems in energy efficiency in buildings depending on climatic conditions. Therefore, in order to provide an easier infection control in naturally ventilated classrooms, the recommended ventilation scenarios after COVID-19 should be examined in terms of energy efficiency and the most suitable periods for natural ventilation should be determined. In this study, the effects of ventilation scenarios developed based on ventilation recommended by international organizations and ventilation scenarios developed based on infection risk during the COVID-19 period on heating-cooling energy demands were analyzed and the most suitable periods for natural ventilation were determined according to climates.Thus, for naturally ventilated classrooms located in different climate zones, the appropriate period in terms of thermal comfort and heating-cooling energy demand for the academic year's work schedule during the COVID-19 pandemic period can be determined.Ventilation rates based on infection risk were determined by two different mathematical models based on the modified Wells-Riley equation that was improved according to SARS-COV-2. The heating-cooling energy demands of the classrooms were calculated according to the heat balance method with the building energy simulation. The proposed method was applied to a naturally ventilated higher education building as a case study. The results show that the differences in the recommended ventilation scenarios after COVID-19 also cause differences in heating and cooling loads. It has been observed that the natural ventilation required after COVID-19 reduces the total energy demand for building heating and cooling between 25.54% and %27.48 in hot and temperate climates and can increase it by 69.59% in cold climates compared to before COVID-19. Other results have shown the importance of determining the Academic Work Year Schedule in terms of energy efficiency in airborne outbreaks such as SARS-COV-2 in line with the periods most suitable for natural ventilation depending on climatic conditions.

Keywords: *Classroom, Cooling energy, COVID-19 pandemic, Heating energy, Ventilation*

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1. INTRODUCTION

Transmission of SARS-CoV-2 can occur through direct contact with infected people or through infected secretions such as respiratory passage droplets (Tang & Wang, 2020). Respiration droplets and aerosol particles can move through the air, as well as stay suspended in the air for a certain distance and time period (Jarvis, 2020). Therefore, the spread of COVID-19 disease caused by the new SARS-CoV-2 virus usually occurs in indoor environments where virus transmission may occur easily (da Silva, 2020; Richardson & Lovegrove, 2021).

During the COVID-19 pandemic, many countries have had to implement some enforcements to ensure infection control in schools and public places with crowded indoor environments such as classrooms. One of these enforcements is closing down the schools temporarily and the development of distance education-work modules, and etc. The sudden and long-term transition to out-of-school learning during the COVID-19 process has had a negative effect on both the education of students and their state of mind (Zviedrite et al., 2021).

WHO (World Health Organization) considers inadequately ventilated places during the COVID-19 process as high-risk in terms of infection risk. Therefore, ventilation has been prioritized to prevent the spread of the SARS-COV-2 virus in learning spaces during the return to face-to-face education. One of the two primary approaches to ventilation is to provide the necessary fresh ventilation rates per person recommended by international organizations such as ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), REHVA (European Federation of Heating, Ventilating and Air-Conditioning Associations) and WHO; the second approach is to provide ventilation rates based on the quantitative airborne infection risk in indoor spaces. For example, although ASHRAE did not specify a clear value for classrooms in its report published during the COVID-19 outbreak, it stated that more minimum ventilation is required compared to the pre-COVID-19 ANSI/ASHRAE 62.1 Standard (ASHRAE, 2021). REHVA recommends a minimum fresh ventilation rate of 8-10 L/s per person in classrooms (REHVA, 2021), while WHO recommends 10 L/s for naturally ventilated buildings other than residential buildings (WHO, 2021), These uncertainties cause contradictions both in terms of infection control in learning spaces and the heating and cooling energy demand required for indoor thermal comfort conditions. While the common point of these recommendations is to increase fresh ventilation rates compared to pre-COVID-19, there is still uncertainty about exactly how much is needed. This uncertainty causes contradictions in terms of both infection control in learning spaces and heating and cooling energy demand required for indoor thermal comfort conditions.

It is easier to apply the ventilation recommendations that emerged during the COVID-19 process in classrooms with mechanical ventilation in real-life conditions than in classrooms with natural ventilation. In classrooms with mechanical ventilation, air flow distribution and fresh

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air rate can be easily controlled by the automation system. In naturally ventilated classrooms, CFD (computational fluid dynamics) or tracer gas decay method is generally used in studies to control ventilation rates with airflow distribution strategies.

Ascione et al. (2021) investigated air distribution strategies with CFD in their study on safe classroom design in infectious diseases such as COVID-19 in a university building. Park et al. (2021) calculated the natural ventilation rates according to the conditions of opening the windows with the tracer gas decay method in a naturally ventilated school building and reported that the ventilation rates required for the classrooms to be safe in terms of the risk of infection during the COVID-19 process can be achieved by natural ventilation.

Previous studies have shown that the ventilation rate and ventilation strategies in naturally ventilated classrooms can be controlled in specific ways. Classrooms, which are usually kept closed due to drafts and external noise, are very vulnerable to virus infection. Moreover, even if natural ventilation rates are controlled, the impact of natural ventilation on indoor thermal comfort can be positive or negative depending on climatic conditions. The negative impact of the blowing sensation for students sitting by the window can be reduced by changing the seating arrangement in classrooms, taking into account social distancing conditions. However, in cases where natural ventilation is required to reduce the risk of infection, the indoor comfort temperature needs to be maintained to prevent thermal discomfort in classrooms. This will also directly affect building energy consumption. To create healthy interiors using low energy, it is vital to make adequate and effective natural ventilation decisions during the building design process. Therefore, it has become even more important to investigate the impact of natural ventilation on building energy performance during the COVID-19 period.

The current air conditioning system of most schools have been scaled according to the conditions before COVID-19. In schools with natural and mechanic ventilation, especially in very cold or hot climates, existing air conditioning systems may be insufficient to meet the demand for heating or cooling energy in changing required ventilation conditions during the COVID-19 period. Therefore, as Park et al. (2021) mentioned, if the ventilation required to reduce the risk of infection during the COVID-19 process is provided by natural ventilation, the effect of ventilation on building energy performance should also be investigated.

Up until today, studies have been conducted on the effect of changing conditions on energy demand in educational buildings during the COVID-19 period with building energy simulation and Monte Carlo method (Ascione et al., 2021; Orosa et al., 2020; Zhang et al., 2020). However, in these studies, ventilation rates were generally determined according to the values in international standards. Kurnitski et al. (2021) stated that fixed ventilation rates in classrooms are not sufficient under any circumstances and therefore a general ventilation criterion based on infection risk should be established with the Wells-Riley model calibrated

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according to SARS-CoV-2. Yılmazoğlu (2020) developed and published a calculation tool for determining COVID-19 infection risk and required ventilation rates in indoor environments using the Wells-Riley equation. As in these examples, the Wells-Riley equation is now widely used in studies analyzing the relationship between the risk of airborne COVID-19 infection and ventilation strategy.

Sutherland et al.(2022) reviewed 142 articles from 4 search databases to examine the existing literature on the effect of natural ventilation on thermal comfort in winter months and found that most studies focused on the evaluation of ventilation conditions, especially in areas that are not naturally ventilated. He also emphasized that there is a significant gap in the existing relevant literature. To the best of our knowledge, no study has examined the effects of fixed ventilation rates recommended by international organizations and infection risk-based ventilation rates on heating and cooling energy loads in naturally ventilated schools. Comparing and analyzing these approaches may contribute to architects, engineers, pedagogues and pandemic researchers to determine energy efficiency strategies that differ according to climates during pandemic periods such as COVID-19 and to create a different working schedule for the academic year according to climates.

By studying the ventilation approaches that emerged throughout the COVID-19 process and reviewing the fundamental theories, formulations, and revisions of ventilation approaches per COVID-19, ventilation rates were calculated in this study according to the classrooms selected for the case study. The influence of ventilation approaches in the COVID-19 process on heating and cooling energy demand in naturally ventilated higher education classrooms in hot humid, hot dry, mild humid, mild dry, and cold climates was then studied. In the conclusion section, various proposals have been offered for the periods when natural ventilation is acceptable in terms of heating-cooling energy demand according to the climates in the COVID-19 process.

2. METHOD

This study has been prepared in order to fill the gap in the existing literature, to provide the most appropriate conditions in terms of energy while making the infection rate the healthiest in schools where ventilation is provided only by natural ventilation, taking into account the energy concept, which is one of the cornerstones of sustainability criteria. While preparing this study, the losses and gains in the energy connection of schools in different climate zones will be determined. In this way, it will be possible to determine the course hours or gaps between classes that can be created according to the climate zones in the new semester. In this way, both healthy, comfortable and the most efficient energy consumption will be realized. For this reason, a sample school was selected in the study and the most used classrooms in the school were examined and analyzed. The work flow diagram is given in Figure1.

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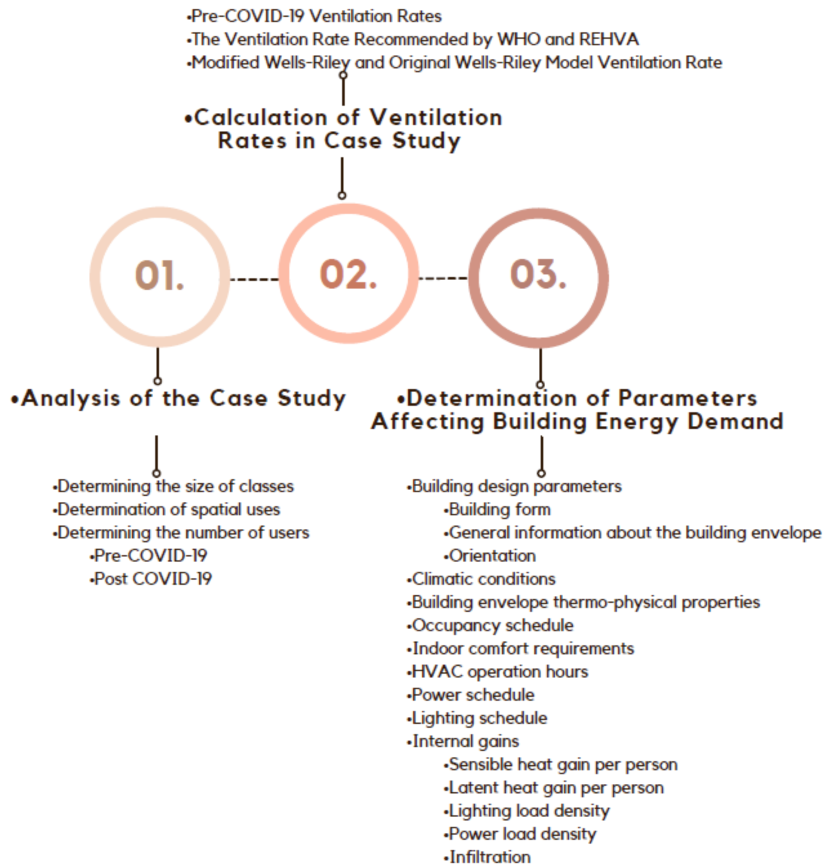

Figure 1. Workflow diagrams.

The proposed method consists of three stages. In the first stage, classrooms representing higher education learning spaces were determined for the case study and the analysis of the case study was performed. At this stage, the dimensions of the classrooms, their spatial use and the number of users were determined according to the social distancing rules for pre-COVID-19 and post-COVID-19.

In the second stage, outdoor air ventilation rates required for classrooms were calculated. The ventilation rates determined according to the fixed ventilation approach after COVID-19 were calculated with the ventilation approach recommended by WHO and REHVA (REHVA, 2021; World Health Organization, 2021). Based on the original Wells-Riley equation and the Wells-Riley equation developed by the COVID-19 Task Force of REHVA's Technology and Research Committee (REHVA, 2021) according to SARS-CoV-2, the ventilation rates determined based on the risk of infection were calculated by Kurnitski et al. (2021) with the equation derived to calculate the ventilation rates.

In the third stage, other parameters affecting the heating-cooling energy consumption of the sample classroom block determined for the case study (such as the design parameters of the classrooms, climatic conditions, thermo-physical properties of the building envelope, occupancy-operation parameters and internal heat gains) were determined. The energy model of the higher education classrooms determined for the case study was created and the heating and cooling thermal loads were calculated for the academic work year schedule according to the ventilation scenarios determined before and after COVID-19. EnergyPlus, (EnergyPlus ™, 2010) an energy analysis and thermal load simulation program developed by the U.S. Department of Energy, was used to calculate thermal loads.

The accuracy of the EnergyPlus software has been previously validated by the Building Energy Simulation Test procedure (BESTEST) (Strand, 2005). EnergyPlus calculates heating-cooling loads (heating-cooling thermal loads) according to the heat balance method algorithm, which takes into account the transient heat conduction in the building envelope and all heat balances on the exterior and interior surfaces (Buratti et al., 2013; Eskin and Türkmen, 2008; Miyazaki et al., 2005). The "Heat Balance Method" is scientifically recognized as one of the most accurate methods for various heat transfer and thermodynamic processes (Pedersen et al., 1997; Yan et al., 2015). The heat balance calculation method is described in detail in the EnergyPlus 9.1.0 Documentation (EnergyPlus™, 2019). The accuracy of the EnergyPlus software has been previously validated by the Building Energy Simulation Test procedure (BESTEST) The steps of the proposed methodology are described in detail in the following sections.

2.1. Analysis of the Case Study

Case studies were conducted on actual room layouts to test recommended ventilation approaches based on infection risk. In this experiment, the classrooms in the Architecture classroom block of the Faculty of Architecture and Design of Erzurum Atatürk University were chosen for the case study. Since mechanical ventilation cannot be used actively in classrooms, the need for fresh ventilation is carried out by natural ventilation method by the windows.

The building consists of three main axes and has three floors. The number and order of classrooms in each axis is the same. There are 3 types of classrooms in each axis. These are architecture studio, small theoretical classroom and large theoretical classroom. The ground and 1st floor plans are the same and there are two architecture studios on each floor. On the 2nd floor, there are 2 large and 1 small theoretical classrooms on each axis. The study covers the classrooms of the 2 main blocks of the architecture department and the analysis was done for a total of 4 architecture studios, 4 large and 2 small theoretical classrooms. The general layout of the building is shown in Figure-2, the 3D visuals of the block and classrooms are shown in Figure-3 and the floor plans and sections of the classroom block are shown in Figure-4.

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Figure 2. Faculty building and its immediate surroundings

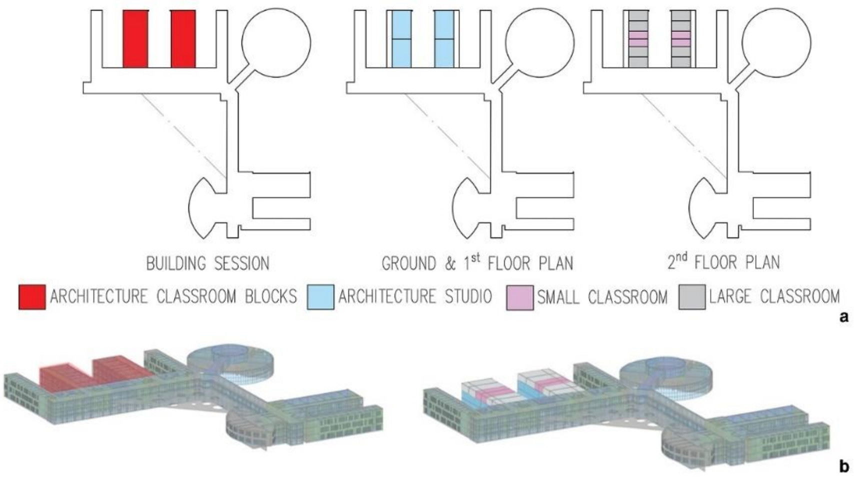

Figure 3. a) Location of blocks and classrooms in the plan b) Location of blocks and classrooms in 3D visual

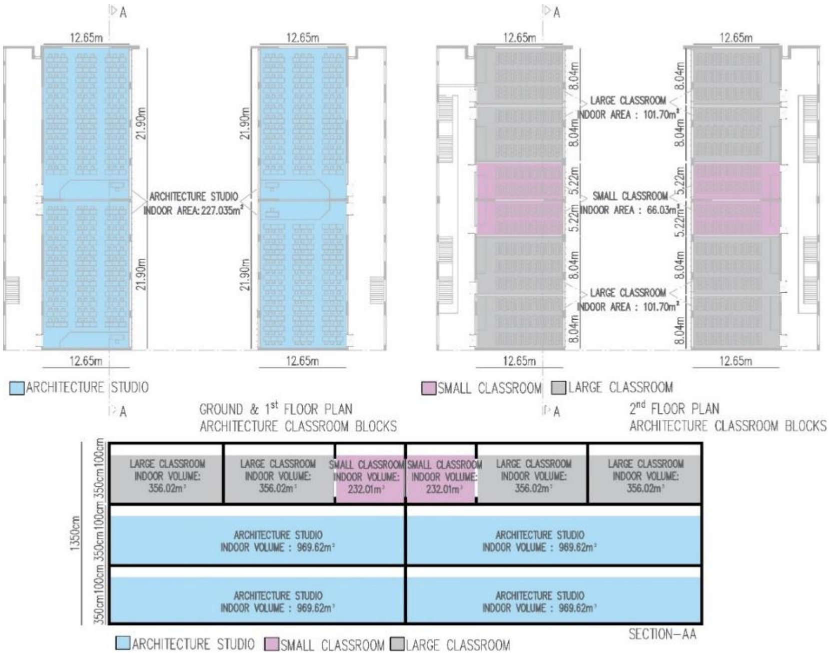

Figure 4. Floor plans and sections of the architecture classroom block

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In terms of the risk of infection after COVID-19, the density of occupancy in classrooms varied compared to before COVID-19 due to social distancing rules. At this stage, while the capacity should be diluted by 50% for large and small theoretical classrooms, it was not necessary to dilute 50% thanks to the large internal volume resulting from the pedogical requirements in the architectural studio classroom. The user density and detailed information of the classrooms are given in Table 1.

Table 1. Location and user density information of classrooms

Classroom	Number of classrooms	Floor space (m^2)	Space Ceiling height (m)	Before COVID-19 conditions		After COVID-19 conditions (Social distancing)	
				Total number of people	Number of people per area (m^2)	Total number of people	Number of people per area (m^2)
Architectural Studio	4	277.035	3.50	108	2.65 m^2	72	3.84
Small Classroom	2	66.004	3.50	54	1.22	27	2.44
Large Classroom	4	101.200	3.50	81	1.25	40	2.54

2.2. Calculation of Ventilation Rates in Case Study Classrooms

In the calculation of the ventilation rates of the classrooms, the standards of the pre-COVID-19 periods, methods developed after-COVID-19, values and guidelines recommended by the institutions were taken into consideration.

2.2.1. Pre-COVID-19 Ventilation Rates

According to ASHRAE 62.1, the minimum air flow in the breathing zone can be 3.8 L/s for lecture theaters, while the minimum air flow according to ISO and EN standards should never fall below 4 L/s per person for health reasons (Khovalyg et al., 2020). In non-residential low polluted buildings, ISO 17772, EN 16798 and EN 15251 specify a value of 4 L/s for category 3 ventilation rates. In this study, 4 L/s per person was accepted as the miminum ventilation rate for pre-COVID-19. Accordingly, 1.55 L/(sm^2) in the architectural studio classroom; 3.27 L/(sm^2) in small theoretical classrooms; 3.19 L/(sm^2) in large theoretical classrooms are required to provide minimum ventilation rates for pre-COVID-19 in learning spaces of which capacity and spatial dimensions are given in the Table 1.

2.2.2. The Ventilation Rate Recommended by WHO and REHVA

The WHO and REHVA proposed the category I ventilation rate (10 l/s per person), which has a higher ventilation rate among 3 categories, referring to the EN 16798: 2019 standard as the minimum ventilation

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requirement in non-hospital and non-residential buildings during the COVID-19 process (WHO, 2021; REHVA, 2021). According to the ventilation approach proposed by WHO and REHVA, the minimum ventilation rate required for learning spaces after COVID-19 was calculated as 2.59 L/(sm^2) in the architectural studio classroom; 4.09 L/(sm^2) in small theoretical classrooms; 3.95 L/(sm^2) in large theoretical classrooms.

2.2.3. Modified Wells-Riley and Original Wells-Riley Model Ventilation Rate

The original Wells-Riley model is shown in Equation (1) (Riley et al., 1978):

$$P_I = \frac{C}{S} = 1 - \exp\left(-\frac{Iqpt}{Q}\right) \quad (1)$$

where P_I is the probability of infection risk; S is the number of susceptible people; C is the number of cases that develop infection; I is the number of infectious persons; t is the duration of the occupancy; q is the quanta emission rate; p is the pulmonary ventilation rate and Q is the volume flow of pathogenic free air. In the original Wells-Riley model, the factors affecting the risk of infection are limited to the parameters specified in the equation.

Kurnitski et al. (2021) derived an equation that can be used directly for ventilation scaling, with the assumption of steady state. In this model, taking into account the surface deposition loss and virus decay of SARS-CoV-2, the external ventilation rate was determined as Q (m^3/h) shown in Equation (2) derived by Kurnitski et al. (2021):

$$Q = \frac{qQ_bD}{ln\left(\frac{1}{1-p}\right)} - \left(\lambda_{dep} + k\right)V \quad (2)$$

Where D is the duration of the occupancy (h); Q_b is the volumetric breathing rate of an occupant (m^3/h); q is the quanta emission rate per infected person (quanta/(h pers)); p is the probability of infection for susceptible persons; V is volume of the room (m^3); λ_{dep} is deposition onto surfaces (1/h); k is virus decay (1/h).

As shown in Equation (3), the amount of inhaled quantum (n) depends on the length of time people stay in the area (D, h), the average of the quantum concentration (C_{avg}) and a person's volumetric respiratory rate (Q_b, m^3/h).

$$n = C_{avg}Q_bD \quad (3)$$

The average concentration is determined as shown in Equation (4), Equation (5) and Equation (6):

$$\mathrm{E} = \mathrm{Iq} \quad (4)$$

$$C(t) = \frac{E}{\lambda V}\left(1 - e^{-\lambda t}\right) \quad (5)$$

$$C_{avg} = \frac{1}{D}\int_0^D C(t)dt = \frac{E}{\lambda V}\left[1 - \frac{1}{\lambda D}\left(1 - e^{-\lambda D}\right)\right] \quad (6)$$

Where E is quanta emission rate (quanta/h); Λv is the outdoor air change rate (1/h); t is time (h). The first order loss amount coefficient (λ, 1/h) for quanta/h is determined according to Equation (7) (Yang & Marr, 2011) below:

$$\lambda = \lambda v + \lambda_{dep} + k \quad (7)$$

Quanta emission amount and volumetric respiratory rate value vary according to activities such as speaking aloud, coughing, and exercising. Therefore, the appropriate value should be determined by examining the studies analyzing the volumetric respiratory rate value and the quanta formation amounts for SARS-CoV-2 according to the activities. The number of susceptible people (S) in the classrooms and the volume of the classrooms (V) are shown in Table 1. The number of cases that develop infection (C or R) in classrooms was accepted as 0.99. The number of people infected with COVID-19 was accepted as one person in classrooms. The parameters in the Wells-Riley equation developed to determine the risk of infection and the references relevant to the values accepted in this study are shown in Table 2.

Table 2. Parameters and accepted values in the modified Wells-Riley model

Parameter	Units	Value	References
Virus decay (k)	h^{-1}	0.32	(Fears et al., 2020; van Doremalen et al., 2020)
Virus surface deposition loss rate (λ_{dep})	h^{-1}	0.30	(Buonanno, Morawska, et al., 2020; Chatoutsidou & Lazaridis, 2019; Diapouli et al., 2013; Miller et al., 2020; Thatcher et al., 2002)
Quanta emission rates (q)	quanta/h	16.50	(Stabile, Pacitto, et al., 2021)
The volumetric breathing rate of an occupant (p or Qb)	(m^3/h)	0.80	(Adams et al., 1993; Binazzi et al., 2006)
The duration of the occupancy (t or D)	h	4	8 AM to 12 PM - 13 PM to 17 PM

Considering the parameters specified in Table 2, the minimum ventilation rates required for the acceptable infection risk level (R=0.99) according to the equation in the modified Wells-Riley model were calculated as: 2.94 L/(s m^2) in the architectural studio classroom; 5.07 L/(s m^2) in small classrooms; 4.89 L/(s m^2) in large classrooms. The minimum ventilation rates required for the acceptable infection risk level (R=0.99) according to the formula in the original Wells-Riley model were calculated as: 3.85 L/(sm^2) in the architectural studio classroom; 6.06

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L/(sm^2) in small theoretical classrooms; 5.85 L/(s m^2) in large theoretical classrooms.

2.3. Determination of Parameters Affecting Building Energy Demand

In order for the proposed study to give accurate results with different data and to be developed with other researches, the variables affecting thermal loads should be determined in detail. Parameters affecting heating-cooling energy demand: building design parameters (building form, general information about the building envelope, orientation, etc.), climatic conditions, building envelope thermo-physical properties, occupancy schedule, indoor comfort requirements, HVAC operation hours, power schedule, lighting schedule, etc. and internal gains (sensible heat gain per person, latent heat gain per person, lighting load density, power load density, infiltration, etc.) are discussed in detail within the scope of the study.

2.3.1. Building Design Parameters

Heat gains and losses in the building are mostly caused by the building envelope. Therefore, the thermo-physical properties of the components forming the building envelope, window wall ratio, building geometric form and orientation directly affect the energy need and energy consumption of the structures. The present classroom block, the classrooms are north oriented, while the corridor is south oriented. There are no windows on the facades in the other two directions. The section and plan showing the building geometry, classroom dimensions and classroom orientations are shown in Figure 1. According to the design parameters of the building, the information of the building shell is given in detail in Table 3.

Table 3. Building design parameters

Number of floors	Classroom block	Ground + 2 floors
Level floor area	Gross floor	44.7 m*18.85 m=842.595 m^2
	Conditioned floor	794.535 m^2
Height	Floor height	4.5 m
	Ceiling height	3.5 m
	Building height	13.5 m
Energy analytical model spaces	Total floor area	4096,45 m^2
	Conditioned classroom floor area	1694,20 m^2
	Unconditioned corridor floor area	707.45 m^2
	Unconditioned ceiling floor area	1694.80 m^2
Energy analytical model volume	Total volume	10110.68 m^3
	Conditioned classroom	5761.71 m^3

	Unconditioned corridor	3086.01 m^3
	Unconditioned ceiling floor	1262.96 m^3
Conditioned classroom facade surface area (North)	Opaque wall area	451.83 m^2
	Window opening area	297.64 m^2
	Window-wall ratio (%)	%68.15
Corridor facade surface area (South)	Gross wall area	573.51 m^2
	Conditioned gross wall area	0.00 m^2
	Window opening area	257.43 m^2
	Window-wall ratio (%)	%44.89
Conditioned other walls facade surface area	East opaque wall facade surface area	135.78 m^2
	West opaque wall facade surface area	132.58 m^2
Roof area	Conditioned roof area	795.69 m^2

2.3.2. Determination of Building Envelope Thermo-Physical Properties

Climate zones in Turkey are divided into 4 climate zones according to the heating degree day method with The Turkish Standard "TS 825 Thermal Insulation Requirements in Buildings" and standards have been introduced in thermal conductivity values for building envelope components (TS 825, 2008). In this study, the building envelope u-values specified in the standards were accepted according to the climate zones in TS 825 regulation. TS 825 heating degree day climate zones and building envelope u values are shown in Table 4.

Table 4. TS 825 Climate Zone and Building Envelope U-Value

TS 825 Climate Zone	Exterior Wall U-Value (W/m^2K)	Slabs on grade U-Value (W/m^2K)	Roof U-Value (W/m^2K)	Window U-Value (W/m^2K)
1. Region	0.70	0.70	0.45	2.4
2. Region	0.60	0.60	0.40	2.4
3. Region	0.50	0.50	0.30	2.4
4. Region	0.40	0.40	0.25	2.4

Solar heat gain coefficient (shgc) and visual light transmission (vlt) value are not specified for windows in TS 825. In this study, the solar heat gain coefficient value was accepted as 0.50 and the visual light transmission value was accepted as 0.71.

2.3.3. Determination of Representative Climate Zones

In studies dealing with the relationship between architecture and te in Turkey, climatic zones are generally classified as 5 different climates:

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hot-humid, hot-dry, moderate-humid, moderate-dry and cold (Ovali, 2020). Therefore, in this study, cities representing all climate types were also included. Other information about the climate servers and climatic characteristics in which the climate data of the selected cities were obtained is shown in Table 5 below. World Meteorological Organization (WMO) weather stations included in EnergyPlus were used to collect climate data for representative cities. EnergyPlus and the World Meteorological Organization both provide access to climate data.

Table 5. Climate data of selected cities and other information on climatic characteristics

City	Latitude (degree)	Longitude (degree)	WMO Weather Stations	Ashrae Climate Zone	TS 825 Climate Zone	Climatic Characteristics
Antalya	36.87	30.73	173000	2A	1	Hot humid
Şanlıurfa	37.13	38.77	172700	2A	2	Hot dry
İstanbul	40.98	28.82	170600	3A	2	Temparate humid
Ankara	39.95	32.88	171300	4A	3	Temperate dry
Erzurum	39.95	41.17	170960	6A	4	Cold

2.3.4. Occupancy and Operation Parameters

The heating-cooling energy demand of higher education institutions may vary periodically due to changing climatic conditions during the year with the building usage program in academic work year schedule for the year. In this study, the academic work year schedule accepted by REVIT AUTODESK for universities based on ASHRAE 90.1-2010, ASHRAE 90.2-2010, ASHRAE 62.1 and CBECS data for schools was taken as reference (*Help Occupancy Schedules Autodesk*). Only during the hours that the classrooms are in use is natural ventilation permitted. It was assumed that the classrooms were not used because there was a lunch break between 12:00 PM and 13:00 PM. It is assumed that the classrooms are used to their full capacity. Parameters affecting building energy loads, simulation input data determined based on ASHRAE 55 (ASHRAE, 2013), ASHRAE 62.1 (A. S. ASHRAE, 2019) and ASHRAE 90.1 (ASHRAE, 2013) standards are detailed in Table 6. The corridor in the classroom block was excluded from the study and its thermal loads were not calculated.

Table 6. Occupancy, lighting and power schedule and internal loads

Parameter		**Value**
Annual occupancy schedule	Spring semester	January 6 – April 5 and April 14 – June 8
	Fall semester	August 25 – December 15
Occupancy schedule on weekdays		8 AM to 12 PM - 13 PM to 17 PM
Lighting schedule		8 AM to 12 PM - 13 PM to 17 PM

Power schedule	8 AM to 12 PM - 13 PM to 17 PM
Sensible heat gain (per person)	73.27 W
Latent heat gain (per person)	58.61 W
Lighting load density	15.07 W/m²
Power load density	10.76 W/m²
Infiltration airflow per area	0.358 L/(s·m²)
Heating set point	21.00 °C
Cooling set point	26.00 °C

3. RESULTS AND DISCUSSION

The annual heating and cooling loads of the classrooms were simulated for all 8760 hours in a 12-month period according to the heat balance method using EnergyPlus™ 9.1.0. Then, in this part of the study, the impact of ventilation approaches emerging after COVID-19 on the heating and cooling energy demand in different climates in the case of natural ventilation in higher education classrooms was analyzed.

3.1. The Effect of Post-COVID-19 Ventilation Scenarios on Heating-Cooling Energy Demand

Figure 5 shows the total annual thermal energy demand of the post-COVID-19 ventilation scenarios based on climates. The climate characteristics of Antalya are that winters are mild and summers are very hot and although rainfall is low, relative humidity is high.

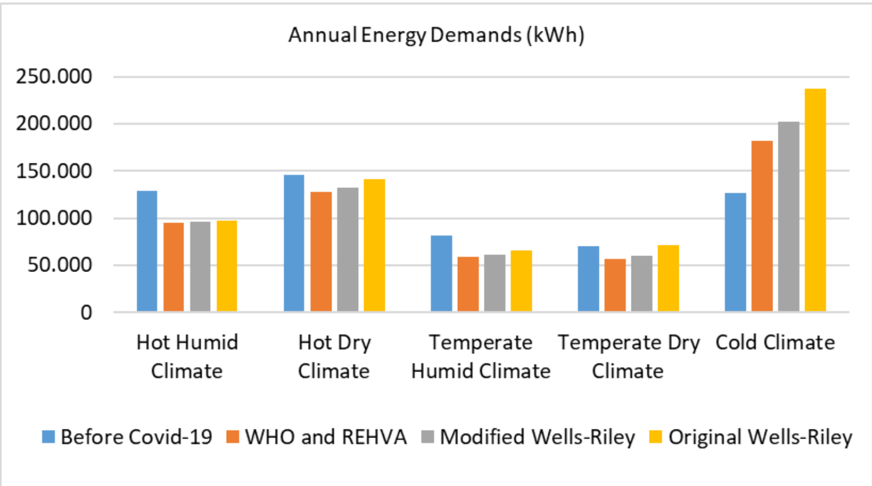

Figure 5. Annual thermal energy demand of ventilation scenarios

According to the figure, the ideal climate for energy demand following COVID-19 was temperate. The cold climate is the worst. The EN 16798-1 ventilation scenario recommended by WHO and REHVA is the most ideal scenario in terms of energy performance in hot and temperate climates. As a result of reducing the cooling load in hot and temperate climates, the increase in natural ventilation following COVID-19 has lowered the total

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energy demand. In cold climates, natural ventilation has been proven to increase energy demand by 86.84%.

3.2. Analysis of Annual Heating and Cooling Energy Demands According to Climatic

In the study, taking the classrooms of a university as an example, the annual heating and cooling energy demands in 5 different provinces with hot humid, hot and dry, temperate humid, temperate dry, cold climate types were analyzed and compared.

3.2.1. Heating and Cooling Energy Demands in Hot Humid Climate

Located in a hot humid climate, Antalya is in the 1st regions according to TS 825 heating degree day, while it is in the Csa (Mediterranean climate) climate type according to the Koppen climate classification. Antalya's climate characteristics are that it is mild in winters and very hot and dry in summers. In these climatic conditions, heating-cooling energy demands by months in naturally ventilated higher education classrooms according to the changing ventilation requirements before and after the COVID-19 period are shown in Figure 6.

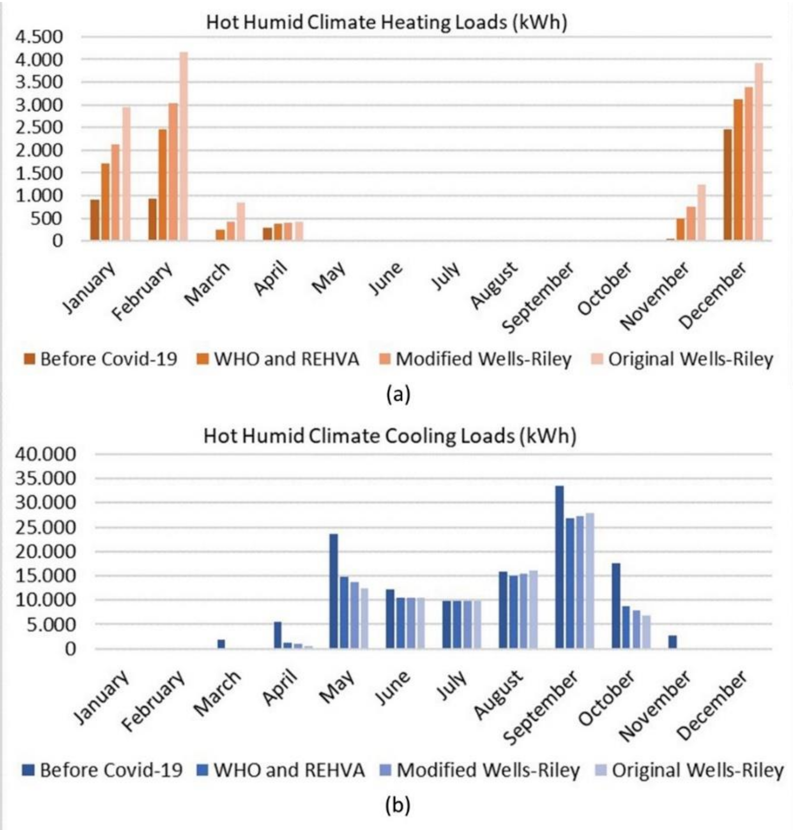

Figure 6. Annual thermal energy demand in hot humid climate; a) heating energy, and b) cooling energy

According to Figure 6, under minimum ventilation conditions before COVID-19, the heating-cooling loads were 75.75 m²/kwh per conditioned building area; 56.39 m²/kwh in the ventilation scenario proposed by WHO and REHVA; 56.59 m²/kwh in the ventilation scenario proposed with the modified Wells-Riley model; 57.70 m²/kwh in the ventilation scenario proposed with the original Wells-Riley model. Increasing ventilation rates after COVID-19 caused a significant decrease in heating-cooling building energy demand compared to the pre-COVID-19 period. The findings showed that increased natural ventilation after COVID-19 may increase the annual heating energy demand by 188.97% with 8.861 kwh compared to the pre-COVID-19 period, and the annual cooling energy demand may decrease by 31.89% with 39.433 kwh. After COVID-19, the demand for heating and cooling energy was realized at least in the WHO ventilation scenario. In the WHO ventilation scenario, total energy demand decreases by 25.54% with 32.789 kwh compared to the pre-COVID-19 period.

In ventilation scenarios after COVID-19, it is seen that the building energy demand decreases depending on the cooling energy demand as the ventilation rate increases in April, May, June 1-9 and October. In the period between September and 26-30 August, it was observed that the increase in the ventilation rate after the WHO and REHVA ventilation scenarios increased the cooling load. Although the increase in natural ventilation rate after COVID-19 in March and November increases the heating load compared to the pre-COVID-19 period, it provides an advantage in terms of total heating-cooling energy demand since it reduces the cooling load more. In this climate, the periods with the lowest total heating-cooling energy demand after COVID-19 in the current academic year are March, November and April. The periods with the highest energy demand are May and September due to the cooling load.

3.2.2. Heating and Cooling Energy Demands in Hot Dry Climate

Şanlıurfa, which is located in hot dry climate, is in the 2nd region according to TS 825 heating degree day, while it is in the Cshk (Mediterranean climate) climate type according to the Koppen climate classification. Şanlıurfa's climatic character is stated as very hot in summer, cool in winter, and as subtropical dry summer climate. In these climatic conditions, heating-cooling energy demands by months in naturally ventilated higher education classrooms according to the changing ventilation requirements before and after the COVID-19 period are shown in Figure 7.

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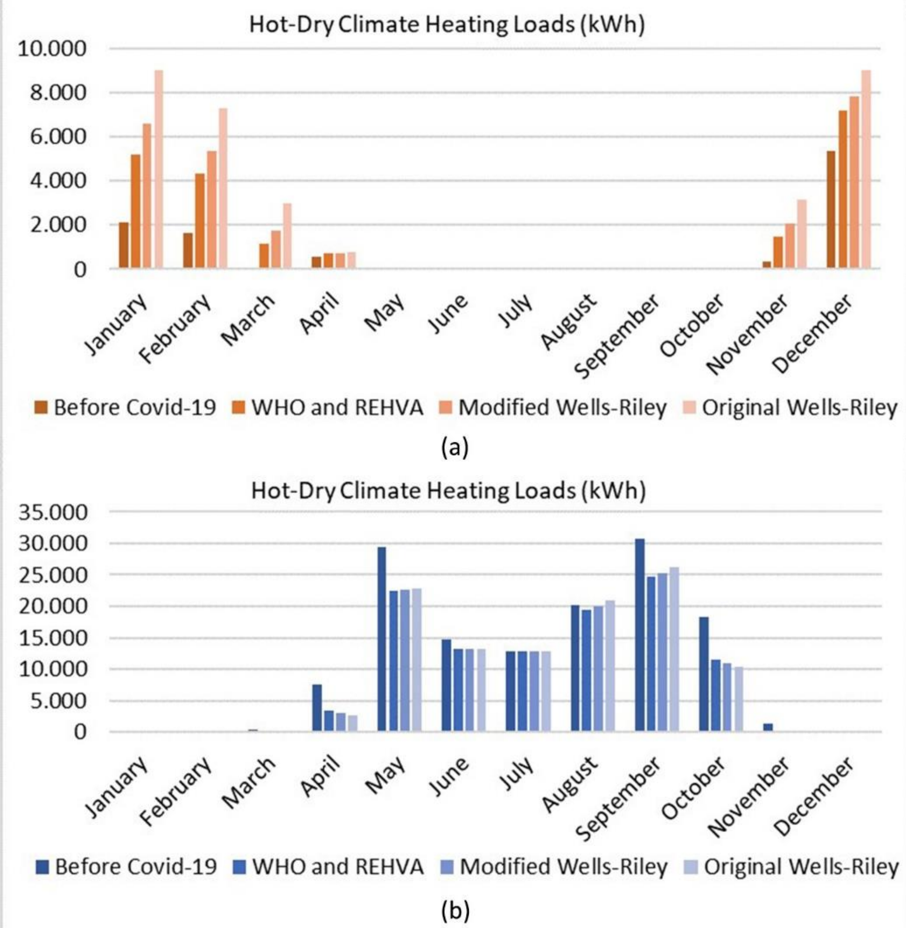

Figure 7. Annual thermal energy demand in hot dry climate; a) heating energy, and b) cooling energy

According to Figure 7, the total heating-cooling energy demand in the hot dry climate was 85.88 m^2/kwh per square meter area conditioned under minimum ventilation conditions before COVID-19; 75.38 m^2/kwh in the ventilation scenario proposed by WHO and REHVA; 78.14 m^2/kwh in the ventilation scenario proposed with the modified Wells-Riley model; and 83.49 m^2/kwh in the ventilation scenario proposed with the original Wells-Riley model.

The findings show that the heating-cooling total energy demand of Şanlıurfa, which is in the 2nd Region according to TS 825 climate class, was 13.38% higher in the pre-COVID-19 period compared to Antalya, which is in the TS 825 1st climate zone; and it has shown that it is 10.22% higher in the post-COVID-19 period. The WHO ventilation scenario was the most ideal ventilation scenario, resulting in a 12.22% decrease in building energy demand by 17,793 kWh compared to pre-COVID-19. From the WHO scenario with the least natural ventilation to the original Wells-Riley model with the most natural ventilation for post-COVID-19, the cooling load increased by 1.41% (1,528 kWh) as the ventilation rate increased and it was observed that the annual heating load increased by 60.86% (12,209 kWh).

The findings showed that increased natural ventilation rates after COVID-19 could reduce the cooling load by 63.14% in April; 23.40% in May; 19.23% in September; and 43.17% in October. In April and October, it is seen that as the ventilation rate increases in ventilation scenarios after COVID-19, the building energy demand decreases depending on the cooling energy demand. In May and September, it was observed that the cooling load increased as the ventilation rate increased in ventilation scenarios after COVID-19. In the period between August 26-30, it is seen that the cooling load exceeded the pre-COVID-19 period in the ventilation performed with the original Wells-Riley. This shows that in May, June, August and September, when the outside temperature is high, natural ventilation can increase the cooling load after a certain point and therefore increase the building energy demand. In March and November, according to the natural ventilation rate after COVID-19, although the cooling load decreases compared to the pre-COVID-19 period, there may be a disadvantage in terms of total energy demand as the heating load may increase more. Since the cooling load is dominant in the hot dry climate, the most advantageous months in terms of total energy demand after COVID-19 are March, November, April, February, December and January, when the cooling need is low.

3.2.3. Heating and Cooling Energy Demands in Temperate Humid Climate

Istanbul city is in the 2nd region according to TS 825 climate class, however, according to the climate classification, it is considered in a temperate humid climate. In this climate, Figure 5 shows the heating-cooling energy demands and final energy use intensities in naturally ventilated higher education classrooms of which ventilation requirements changed before and after the COVID-19 period.

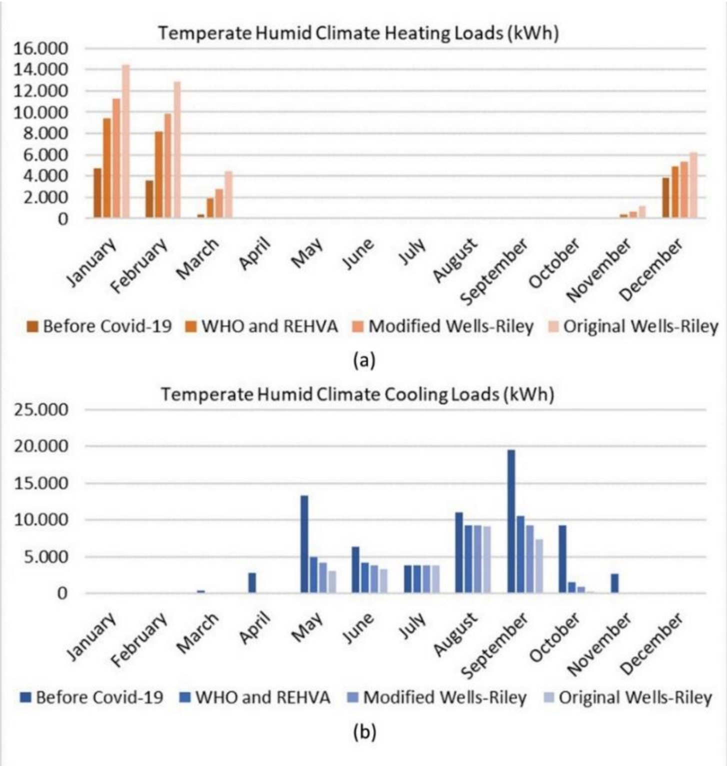

Figure 8. Annual thermal energy demand in temperate humid climate; a) heating energy, and b) cooling energy

According to Figure 8, in temperate humid climate, the total heating-cooling energy demand was 48.32 m^2/kwh per square meter area conditioned under minimum ventilation conditions before COVID-19;

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35.03 m^2/kwh in the WHO and REHVA ventilation scenarios; 36.14 m^2/kwh in the modified Wells-Riley ventilation scenario; and 39.02 m2/kwh in the original Wells-Riley ventilation scenario. The WHO ventilation scenario was the most ideal ventilation scenario, resulting in a 27.48% decrease in building energy demand by 22.500 kWh compared to pre-COVID-19. Compared to hot humid and hot dry climate, the heating-cooling energy demand in all ventilation scenarios is less in temperate humid climate.

In ventilation scenarios after COVID-19, it is seen that the building energy demand decreases depending on the cooling energy demand as the ventilation rate increases in April, May, June 1-9, August 26-30, September and October. The continuous increase in natural ventilation during these periods has provided an advantage in terms of energy efficiency. In March and November, heating-cooling energy demand varies according to ventilation rates, as there is a need for both heating and cooling according to ventilation rates. For example, in Novembe, in all ventilation scenarios after COVID-19, although the cooling load decreases compared to the period before COVID-19, it is seen that as the ventilation rates increase, the heating load increases and the total building energy demand increases accordingly. In March, ventilation rates after COVID-19 increase the energy demand of the building as it increases the heating load similarly as in winter. In this climate, in the current academic year, the periods with the lowest total heating-cooling energy demand after COVID-19 are April, October and November. The periods with the highest energy demand are January, February, September and 26-30 August, depending on the ventilation scenarios.

3.2.4. Heating and Cooling Energy Demands in Temperate Dry Climate

Ankara, which is in this climate, is in the 3rd region according to TS 825. In this climate, Figure 9 showing the heating-cooling energy demands and final energy use intensities in naturally ventilated higher education classrooms of ventilation requirements changed before and after the COVID-19 period is given below.

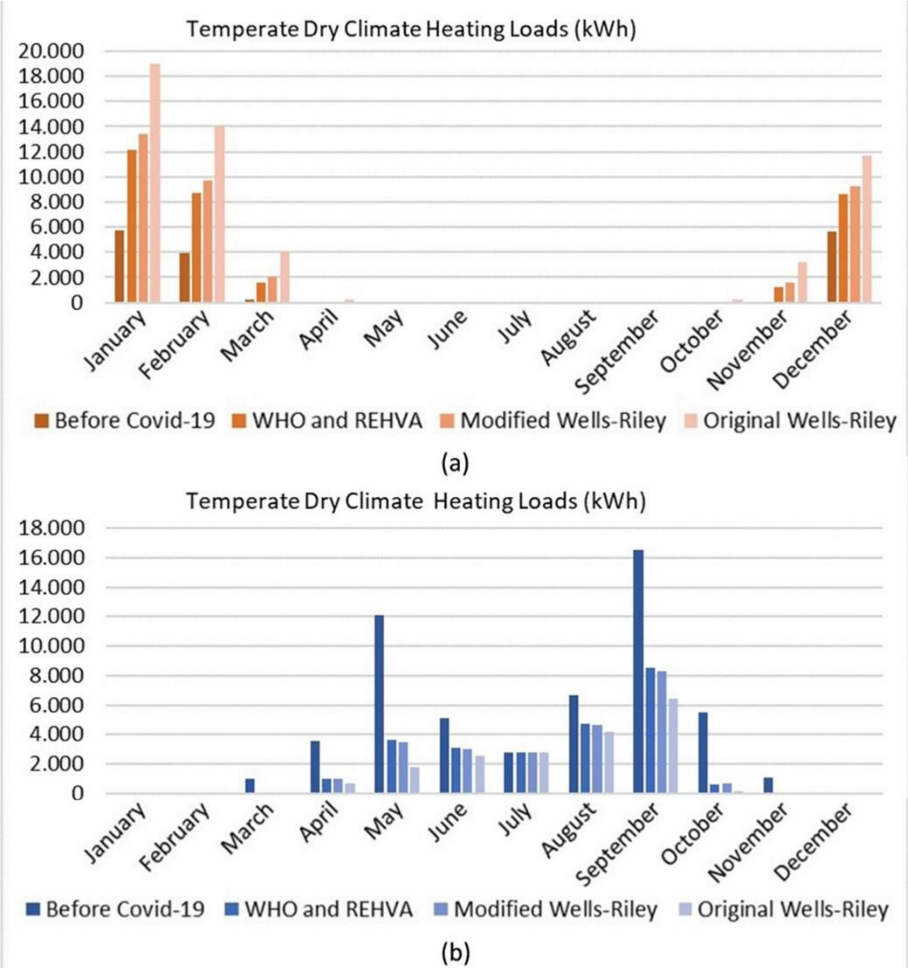

Figure 9. Annual thermal energy demand in temperate dry climate; a) heating energy, and b) cooling energy

According to Figure 9, in temperate humid climate, the total heating-cooling energy demand was 41.20 m^2/kwh per square meter area conditioned under minimum ventilation conditions before COVID-19; 33.46 m^2/kwh in the WHO and REHVA ventilation scenarios; 35.40 m^2/kwh in the modified Wells-Riley ventilation scenario; and 41.81 m^2/kwh in the original Wells-Riley ventilation scenario. The WHO ventilation scenario has been the most ideal ventilation scenario, resulting in a 18.77% decrease in building energy demand by 13108 kWh compared to pre-COVID-19. In temperate dry climate, total heating-cooling energy demand in all ventilation scenarios except the original Wells-Riley ventilation scenario was less than in other climates.

In temperate dry climate, ventilation rates significantly change the heating-cooling load. In the original Wells-Riley ventilation scenario, the heating load increased by 237.80% with 36.845 kwh compared to pre-COVID-19, while the cooling load decreased by 65.92% with 35.811 kwh compared to pre-COVID-19. In temperate dry climate, the original Wells Riley ventilation scenario increased the annual heating load, leading to an increase in building energy demand compared to before COVID-19. Unlike other climates, in temperate dry climate, there was an increase in a ventilation scenario for the first time after COVID-19 compared to the minimum ventilation conditions before COVID-19.

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In the post-COVID-19 scenarios in the Ankara climate, it is seen that the cooling load decreases as the ventilation rate increases in April, May, June 1-9, August 26-30, September and October, and this reduces the total building energy demand. In March and November, heating-cooling energy demand varies according to ventilation rates, as there is a need for both heating and cooling according to ventilation rates. In these months, the increase in ventilation rates after COVID-19 caused the total building energy demands to increase compared to before COVID-19, as the heating load increased. In this climate, the periods with the lowest total heating-cooling energy demand after COVID-19 in the current academic year are October, April, March, November and May. The periods with the highest energy demand are January, February, December and September.

3.2.5. Heating And Cooling Energy Demands in Cold Climate

According to TS 825, Erzurum province is in the 4th region, in the cold climate. In this climate, Figure 10 showing the heating-cooling energy demands and final energy use intensities in naturally ventilated higher education classrooms of ventilation requirements changed before and after the COVID-19 period is given below.

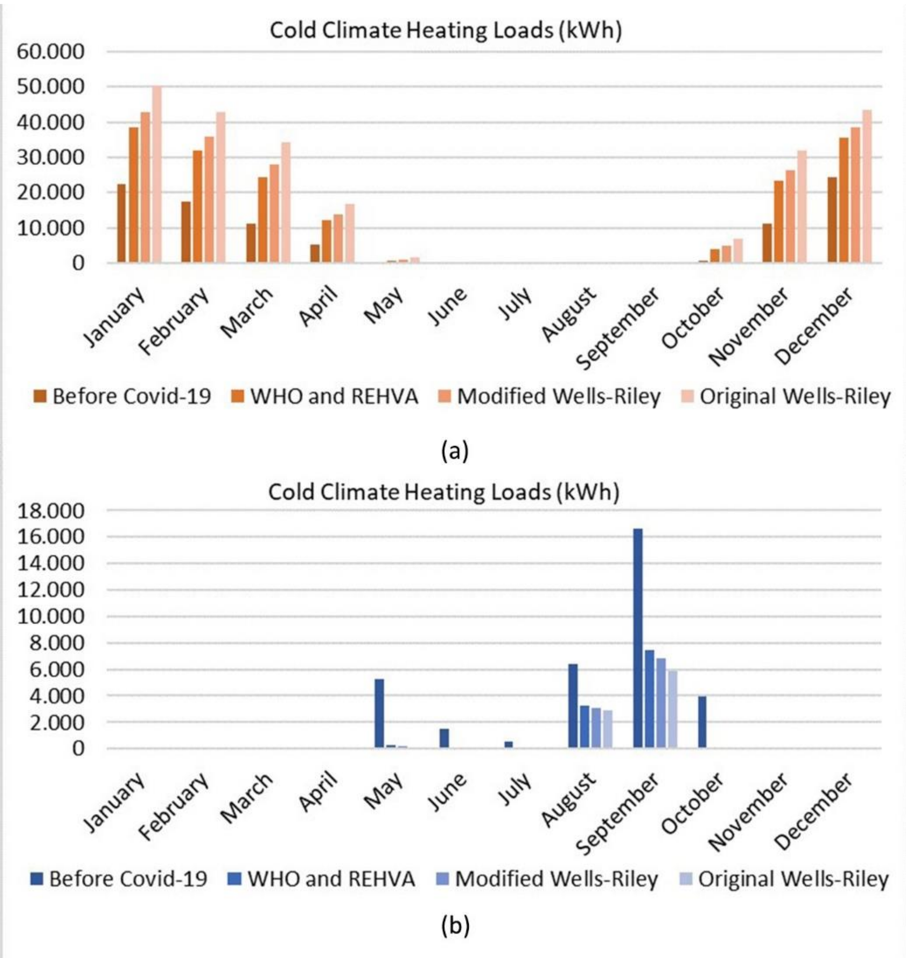

Figure 10. Annual thermal energy demand in cold climate; a) heating energy, and b) cooling energy

According to Figure 10, in cold climate, the total heating-cooling energy demand was 82.51 m^2/kwh per square meter area conditioned under minimum ventilation conditions before COVID-19; 107.14 m^2/kwh in the WHO and REHVA ventilation scenarios; 119.10 m^2/kwh in the modified Wells-Riley ventilation scenario; and 139.94 m^2/kwh in the original Wells-Riley ventilation scenario. In the cold climate, unlike other climates, there has been a significant increase in building energy demands in all post-COVID-19 ventilation scenarios compared to pre-COVID-19. The who ventilation scenario after COVID-19 was the most ideal ventilation scenario, leading to an increase in building energy demand of 41,733 kWh by 29.85% compared to before COVID-19. In the modified Wells-Riley model ventilation scenario, the increase in building energy demand compared to before COVID-19 was 44.33%, while the original Wells-Riley model increased by 69.59%.

In the current academic calendar year, in the pre-COVID-19 minimum ventilation scenario, there was an energy requirement for cooling in May, June 1-9, August 26-30 and September. After COVID-19, there was a significant decrease in cooling loads with the increase in ventilation rates. Therefore, the least energy demand after COVID-19 occurred in June 1-9, May, August 26-30, October and September. The highest energy demand is in January, December, February, March and November, when the heating load is dominant.

4. FINDINGS AND DISCUSSION

As a result of the studies, in the 3 ventilation scenarios proposed after COVID-19, the highest ventilation rate for the classes in the case study was obtained with the original Wells-Riley model, while the lowest ventilation rate was obtained in the ventilation scenario proposed by WHO. In the 3 post-COVID-19 recommended ventilation scenarios, the highest ventilation rate for the classes in the case study was obtained with the original Wells-Riley model, while the lowest ventilation rate was obtained in the WHO recommended ventilation scenario. The results are shown in Figure 11. The surface deposition loss and virus decay parameters of the virus in the modified Wells-Riley model caused the natural ventilation rates required for the acceptable risk of infection to decrease by 16.33% to 23.63% in the modified Wells-Riley model compared to the original Wells-Riley model. This also showed that the parameters affecting the probability of infection (omicron, alpha, beta variant, etc.) will affect the building energy demand as they will change the ventilation rate.

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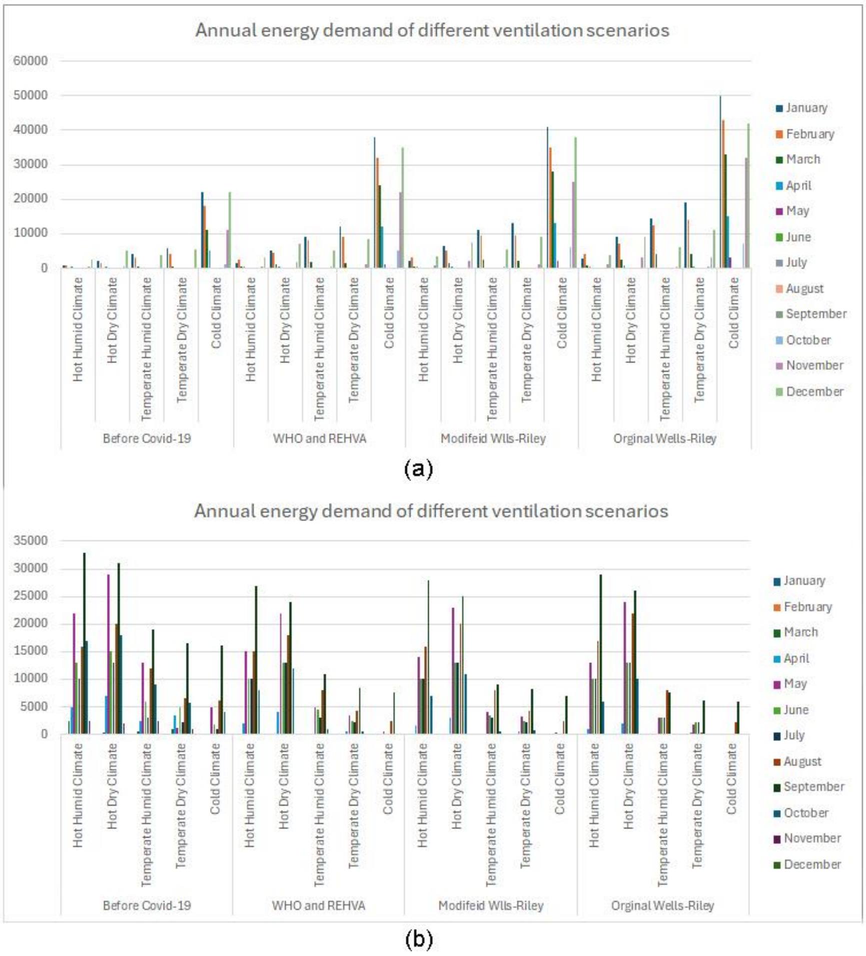

Figure 11. Annual energy different ventilation scenarious; a) heating energy, and b) cooling energy

Annual heating-cooling building energy demands, which were determined based on the ASHRAE, were calculated for 5 different climates according to the occupancy schedule of the classrooms between 6 January-5 April, 14 April - 8 June, 25 August - 15 December, according to the academic year work schedule. If the required outdoor airflow is provided by natural ventilation after COVID-19, the total heating-cooling building energy demand decreased between 23.82% (30,572 kwh) and 25.54% (32,789) in hot humid climate; between 2.78% (4,056 kwh) and 12.22% (17,793 kwh) in hot dry climate; and between 19.23% (15748 kwh) and 27.48% (22500 kwh) in temperate humid climate compared to the pre-COVID-19 period. In temperate dry climate, the demand for heating and cooling energy after COVID-19 decreased by 18.77% (13108 kwh) in the WHO ventilation scenario compared to the pre-COVID-19 period, and by 14.08% (9836 kwh) in the Modified Wells-Riley ventilation scenario, but increased by 1.48% (1034 kwh) in the original Wells-Riley ventilation scenario compared to the pre-COVID-19 period. In case of ventilation scenarios after COVID-19 in cold climate, heating-cooling energy demand increased by 29.85% (41733 kwh) and 69.59% (97292 kwh). Increased natural ventilation after COVID-19 can provide advantages in terms of both building energy demand and infection control in hot and temperate climates.

According to TS 825 climate classification, The heating-cooling energy demand in the hot dry climate, which is in the 2nd Region according to the TS 825 climate classification, is 13.38% higher in the pre-COVID-19 period than the heating-cooling energy demand in the hot humid climate, which is in the 1st Region according to TS 825 climate class, and in the post-COVID-19 period, it is 10.22% higher in the hot dry climate. This shows that the climatic classification in the TS 825 standard is not correct to divide it into zones only according to heating degree days. The TS 825 climate classification should be determined by reconsidering the heating and cooling degree the day, and the building envelope u values should be re-determined according to this climatic classification.

If the natural ventilation required after COVID-19 is carried out, the most suitable climate in terms of energy efficiency has been temperate dry and temperate humid climate. The most disadvantaged climate for the continuation of education was the cold climate. In the WHO ventilation scenario in temperate dry climate, the annual heating-cooling total energy demand was 56703 kwh, while it was 181,533 kwh with an increase of 220.14% in cold climate. Differences in energy demand arising according to climatic characteristics have shown that energy efficiency strategies should be addressed according to climates.

Since it is not easy to control the ventilation rates in naturally ventilated classrooms, the work schedule of the academic year in the COVID-19 pandemic period can be determined according to the periods when natural ventilation can be applied more easily in terms of thermal comfort and heating-cooling energy demand. In hot humid and hot dry climate, the most ideal months for energy demand after COVID-19 were March, April, November, January, February and December. In temperate humid and temperate dry climate, the most ideal months for energy demand after COVID-19 are April, November, October, March and May. In the cold climate, the most ideal months for energy demand after COVID-19 are May, October, September, June, July and August. While September provides an advantage in cold climate, it is disadvantageous in terms of energy efficiency as it increases the cooling load in hot and temperate climates. Appropriate periods for ventilation vary according to climates, so the work schedule of the academic year in the COVID-19 pandemic process should be determined separately according to climates.

5. CONCLUSION

This study examines and compares the annual thermal loads in hot humid, hot dry, temperate humid, temperate dry and cold climates if the ventilation recommended to reduce the transmission of SARS-COV-2 virus in indoor environments during the COVID-19 pandemic period is done with natural ventilation.

Today, many schools do not have mechanical ventilation systems, and in schools with air conditioning systems, the system capacity may be insufficient for increased energy demand in COVID-19 pandemic conditions, as the system capacity is determined according to the

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conditions before the COVID-19 pandemic. Since the installation and use of additional air conditioning systems to meet the increasing energy demands will be costly, especially in countries with limited resources, strategies to reduce energy demand should be developed according to the current design conditions and climatic conditions of the school. Therefore, schools with natural ventilation should be both safe in terms of infection and able to respond to changing energy demands in terms of thermal comfort for a sustainable education in extraordinary events such as pandemics. Therefore, it is necessary to develop building energy systems that can be adapted by reviewing energy demands according to existing systems.

Since it is not easy to control ventilation rates in naturally ventilated classrooms, or when there is no need to add an air conditioning system, the academic year's work schedule can be determined according to the periods when natural ventilation can be applied more easily in terms of thermal comfort and heating-cooling energy demand. Apart from the system change for this purpose, the work schedule of the academic year should be determined separately according to climates.

In order to improve the current study, since the amount of fresh air supplied to the indoor environment by natural ventilation cannot be easily calculated and is difficult to evaluate in real life conditions, the current method can be further improved with CFD simulations and tracer gas method and more comprehensive studies can be carried out.

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Resume

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