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Implementing the Integrated Climate Data Analysis through Hands on Experiments and Jigsaw Methodology to Enhance the Attainment of Learning Outcomes in the Climate-Responsive Architecture Course in Architectural Education

S M Vidhyasankari[1], I Chandramathy[2]
[1,2]Department of Architecture, Thiagarajar College of Engineering, Madurai
[1]smvsarch@tce.edu,
[2]cmarch@tce.edu

Abstract : As climate change poses unprecedented challenges to the built environment, architectural education must adapt to equip future architects with the necessary knowledge and skills to design climate-responsive buildings. This research explores the implementation of an innovative pedagogical approach in the climate-responsive architecture course, aimed at enhancing student's learning outcomes through the integration of climate data analysis, hands-on experiments, and the jigsaw methodology. The study focuses on a cohort of architecture students engaged in a semester-long course specifically designed to address climate-responsive architectural concepts and principles. The results suggest that the integrated approach significantly improves student's comprehension of climate-responsive architectural design principles and their ability to apply these principles to real-world design scenarios. The hands-on experiments and collaborative learning encourage participation, critical thinking, and creativity, while the jigsaw methodology encourages an interdisciplinary understanding of varied climate scenarios.The findings of this study contribute to the ongoing discourse on innovativeteaching methodologies in architectural education and provide valuable insights into the integration of climate-responsive design principles. By cultivating a generation ofarchitects equipped with climate-responsivedesign skills, architectural education can effectivelycontribute to mitigating the impacts of climate change and creating sustainable built environments for the future.

S M Vidhyasankari
Department of Architecture,
Thiagarajar College of Engineering, Madurai
smvsarch@tce.edu,

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1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) (Bernstein, et al., 2008), buildings contribute significantly to the greenhouse gas (GHG) emissions that are causing climate change. Climate change is the single most serious environmental problem confronting the planet. This is especially critical for tropical nations like India, where it has contributed to an increase in global temperature of 0.08 degrees Celsius between the 1850s and 2021(Jones, et al., 2023). Our ability to reduce the effect of buildings on climate change is essential to our continued survival. Implementing strategies like Sustainable Urban Planning, improving energy efficiency in buildings, Climate Adaptation, Renewable Energy Promotion, will require coordinated efforts from governments, construction sectors, industries, communities, and individuals worldwide. It is essential to act swiftly and ambitiously to mitigate the impacts of climate change and safeguard the planet for future generations.

Architects and architecture students play a crucial role in reducing climate change by incorporating sustainable design principles and practices into their projects. Their work can have a significant impact on reducing GHG emissions, promoting a greener and a more sustainable future. Students in architecture programmes must learn how to create structures that are more environmentally-friendly and responsive to the climate. By imparting a strong foundation in climate concepts and sustainable design principles, architecture schools can empower the next generation of architects in creating low energy demand buildings which in turn helps in creating more resilient and environmentally conscious buildings, and contributing to a more sustainable future.

The design studio is considered the pivot of the architectural curriculum. The design studio is meant to be the culmination of all the theory and theory-cum-studio courses. However, due to the gap between theory, research and practice, this specific objective may not be fulfilled effectively most of the time. The adoption of certain integrated active learning techniques could bridge this gap.

Active learning is broadly described as an instructional strategy involving students in learning where it demands students to engage in meaningful learning activities while also reflecting on their actions (Bonwell & Eison, 1991). While this definition could encompass traditional tasks such as assignments, active learning in practice, refers to activities that are introduced into the classroom. The primary goal of active learning is to move away from a passive learning model where students are merely recipients of information and instead create a dynamic learning environment where students take an active role in constructing their knowledge.Various factors like socio economic conditions, peer pressure and impression of the institute influences the students interests towards the studies. Hence one way teaching will not be sufficient to achieve the best result from the students (Jha, 2020).

Active learning requires students to do meaningful learning activities and think about what they are doing (Felder & Brent,2009). Collaborative learning is an instructional method in which students collaborate in small groups to accomplish a common objective. This category of learning includes all group-based learning approaches. Collaborative learning emphasizes student engagement for the purpose of learning. Recent studies indicate a decline in students' physical attendance during lecture hours, prompting researchers to develop student-centered learning methods to actively engage them (Bhagavanulu, 2020)..

The learning pyramid by the National Training Laboratories Institute for Applied Behavioral Science at their main campus in Bethel, Maine, USA is a popular educational concept that represents various methods of learning and their respective retention rates as shown in Fig 1 (Al-Badrawy et al, 2017;Lalley et al 2007).. It suggests that different teaching and learning approaches have varying degrees of effectiveness in helping learners retain information over time. This concept is often used to guide educators in selecting appropriate instructional methods to maximize knowledge retention. The Jigsaw methodology is a kind of Collaborative learning that is mostly based on the phenomenon described in the final step of the learning pyramid(Huang, et al., 2013; Buhr,et al.,2014; Berger et al, 2015). This is a group activity in which the student learns through material presented and discussed about a certain topic or concept while keeping in mind that they must teach or explain it to their colleagues. As a result, the Jigsaw exercise also fulfills the 5th, 6th and 7th levels of the learning pyramid, where the average retention percentage ranges from 50% to 90%. This exercise also takes special care of student comfort. Students are highly

Fig. 1 : Learning pyramid (Adapted from National Training Laboratories Bethel, Maine, USA)

conscious and hesitant to explain or present the notion in front of their teacher or someone who is more knowledgeable in that field than them. However, when students are required to explain or present the same topic to their colleagues in their group, they feel quite comfortable, and other students are not reluctant to ask their doubts to their peers.

Teaching climatology in a conservative way holds the students back from thinking climatically during the initial stages of design especially during the design conception stage. This makes the climatic aspects to be dealt as an add-on rather than an integral component of the design. The culture of integral planning can only be instilled when the topic is treated practically with more hands-on investigations, both quantitative and qualitative. Climate change poses significant challenges to the architectural industry, necessitating the integration of climate-responsive design strategies into architectural education. This proposed pedagogy enables students to analyze climate data and assess its implications on architectural design decisions. It facilitates the understanding of climatic variables, such as temperature, humidity, solar radiation, and wind patterns, and their impacts on building performance. By engaging students in data-driven analysis, they gain valuable insights into the complex relationship between climate and built environment.

In our institution, the topic of climate-responsive architecture was covered in the very second semester of architectural education. This makes them getting introduced to climate-responsive architecture along with the single space building design. Therefore, as novices, their understanding of the environment and of architecture is very nascent and fragile, but it may be positively molded with the aid of carefully thought-out practical modules. The foundational physics that students learned in their high school served as the basis for the practical modules. The hands-on experiment components provide students with practical experiences, allowing them to explore the effects of various design interventions on climate responsiveness. Through interactive activities, such as building scale models, and testing materials, students develop a deeper understanding of the impact of design choices on thermal comfort, and energy efficiency. The complexity of the assignments is increased intentionally as they proceed further. The main objective of the devised assignments is to give the students a better understanding about the influence of the climatic factors on the built forms. The quantification of the climatic parameters of the given spaces along with a questionnaire survey conducted among the users of the space gives a better picture about the relationship between the climate, built forms and the comfort levels.

The objective of using jigsaw pedagogy for climate-responsive architecture is to promote cooperative learning and problem-solving in the context of designing climate sensitive and adaptive buildings. Jigsaw pedagogy as a cooperative learning technique is adopted where students work together in small groups, with each member becoming an expert on a specific topic and then sharing their knowledge with the rest of the team. In the context of climate-responsive architecture, JIGSAW, an innovative teaching methodology can be highly effective for several reasons. The Jigsaw methodology further enhances the learning process by fostering collaborative learning and knowledge sharing among students. Jigsaw methodology significantly improves students' problem-solving abilities and analytical skills(Singh et al 2023). (Dhage et al 2016), Dhage et al (2016),in their work on Jigsaw process for teaching courses in the engineering disciplineconcluded that JIGSAW facilitates life-long learning capability which is a key attribute for engineering graduates (Reba, et al.,2022).

By dividing the students into diverse groups, each focusing on a specific climate-related topic, students become experts in their area and then share their knowledge with peers from other groups. Pianta, 2016 confirms that these frequent consistent interactions will have positive effects in student's learning outcomes(Bhamre et al, 2022).This collaborative learning approach encourages active engagement, critical thinking, and a holistic understanding of climatic concepts and climate-responsive architectural design principles.This technique is unique as it makes students accountable for their own progress while also fostering a sense of ownership for their team(Pusawale, 2020).

This paper proposes a novel approach to enhance learning outcomes in the climate-responsive architecture course by implementing an Integrated Climate Data Analysis through hands-on experiments along with the Jigsaw methodology.

2. Methodology

The proposed methodology aims to enhance the

Table 1 : Courseoutcome For The Course Climate Responsive Architecture

COs	Course Outcomes
CO1	Infer the influence of climatic factors on built environment
CO2	Identify the comfort zones based on the climatic factors for tropical conditions using mathematical formulas and comfort charts.
CO3	Apply the concepts of heat exchange process in buildings and thermal balance equations to analyze heat flow through different building skins
CO4	Analyze the impact of shading devices on thermal performance of buildings using sun path diagrams and solar shading masks
CO5	Analyze various climate responsive design strategies for tropical climates using Mahoney Table to achieve the maximum human comfort
CO6	Assess the effects of site, sun & wind on the built environment using physical models and climate analysis software.

attainment of learning outcomes in the Climate-Responsive Architecture Course by incorporating integrated climate data analysis, hands-on experiments, and the jigsaw methodology. By combining these approaches, students will be exposed to a comprehensive learning experience that fosters a deeper understanding of climate-responsive architectural principles. The course Climate-Responsive Architecture is well-structured with specific learning outcomes that align with the course objectives, such as understanding local climate conditions, designing for energy efficiency, and employing passive design strategies. The course is designed in such a way that it has more practical exercises with six course outcomes from CO1 to CO6 incorporating bloom's taxonomy level where; CO1 addresses Understand level, CO2 and CO3 addresses Apply level, CO4 and CO5 addresses Analyze level, and CO6 addresses the Evaluate level as given in Table I.

In order to evaluate the efficiency of the proposed pedagogy, a test was conducted with students of previous batch (Group A of 2021 Batch) who were exposed to climate concepts through conventional pedagogy and with the students of current batch (Group B of 2022 Batch) who were exposed to climate concepts through proposed pedagogy. The test consisted of 20 questions covering all CO's from CO1 to CO6.

3. Implementation Of Jigsaw Technique

The conductance of the climate responsive architecture course is shown in Fig.2. The course started with explaining the course plan and assignment plan for the even semester 2023. In the first stage, students were introduced to various

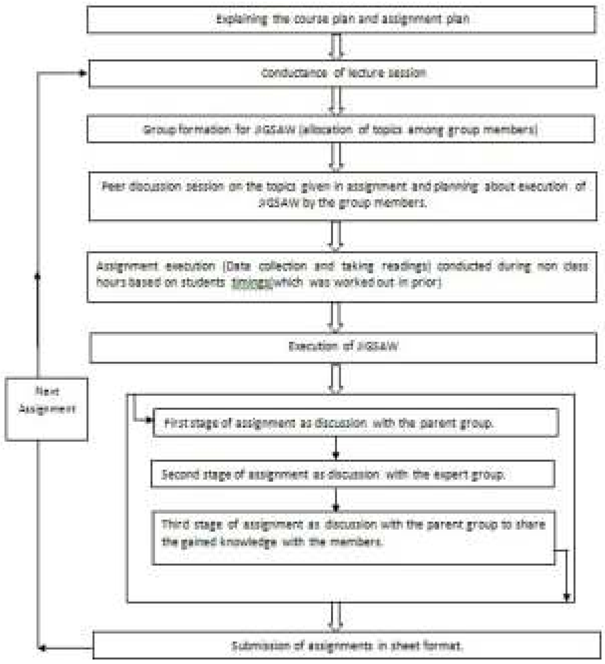

Fig. 2 : Course Implementation Plan for climate responsive Úrchitecture course

theoretical concepts of climate, sources of climate data, including local weather patterns, temperature, humidity, solar radiation, and prevailing winds, and made them explore how to access and interpret this data using specialized tools and software.

In the second stage JIGSAW activity was adopted as an instructional strategy. Before beginning the activity, students were familiarized with the theoretical ideas of the Jigsaw technique, such as the concept of parent and expert groups, group formation guidelines, and the benefits of the Jigsaw technique. Initially students were formed into groups and these groups were called parent groups. Each parent group had four to five members and different topics were allotted to each group member as illustrated in Fig.3.The groups were reconfigured so that each new group consists of one member from each parent group and are referred to as the Expert group. Parent groups initially had discussions with the faculty for clarifications on the given topic; secondly members start working on their specific topics. Members from all groups dealing with the same topics gather to discuss their selected topic for further investigation before returning to the parent group. With their gained knowledge on specific topic, each member educates the other members about their expertise topic as shown in Fig.4. This arrangement ensures that each group has representatives with expertise in different aspects of the chosen topic.Among four hours of a

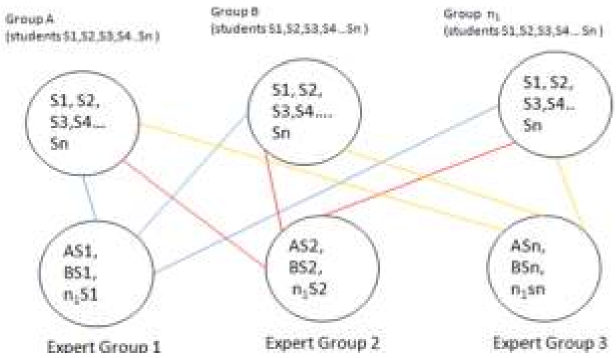

Fig.3 : Formation of groups based on JIGSAW framework

Fig.4 : Image Showing JIGSAW Activity Conducted During theClass
a. Lecture session by the faculty
b. Discussion within parent group
c. Discussion within expert group,
d. Discussion with parent group
e. Discussion with parent group,
f. Discussion with faculty

week, each group was given one hour for initial discussion and to work on the structure of the team work. Next one hour for the team members to research on their given topic. The second day of the week, the first one hour allotted for the expert group discussion for clarification and dissemination of knowledge on selected topic. Then next one hour for discussion within the parent group.The student groups were given practical exercises including Hands-on experiments, model building, and simulations in order to reinforce the theoretical concepts learned from the initial lectures. The practical exercises were planned considering all the COs and the students were informed about the schedule of exercises in advance as given in Table II. In the third stage, Expert groups discussed the impact of different architectural design

Table 2: List of assignments – pedagogy adopted, methodology and outcomes

Assignment 1	
Assignment Topic and Pedagogy adopted	Computing overheated and under-heated periods using isopleth for a chosen climatic zone - This assignment is carried out using JIGSAW framework
Objective	To estimate the hourly temperature, isopleth and overheated or under-heated period.
Methodology	A city belonging to a particular climatic zone (as per NBC) was selected by each group. The climatic data was to be collected from the Indian meteorological department.
Topics of Discussion	1. Psychrometric 2. Isopleths 3.Nomogram 4.Hourly temperature
Course Outcome Covered	CO2 - Identify the comfort zones based on the climatic factors for tropical conditions using mathematical formulas and comfort charts.
Assignment 2	
Assignment Topic and Pedagogy adopted	Thermal Comfort Analysis - This Assignment w as carried out to measure climate parameters using hands-on instruments, thermal comfort questionnaire survey and JIGSAW framework.
Objective	To associatethe relationship between factors of climate and the built environment.
Methodology	The study of climatic factors involves the measuring of the components like Air temperature, Relative humidity, Air velocity, Radiation And surface temperature using instruments or the equipment. After measuring the components for the given spaces, the students were ma de to discuss the correlation between the climatic factors within their parent group. The influence of the factors between different spaces and its components were discussed within the expert groups. The inferences arrived again with the discussion with the parent group.
Topics of Discussion	1. Air temperature 2.Relative humidity 3.Air velocity 4.Radiation (Mean Radiant Temperature)
Course Outcome Covered	CO1 - Infer the influence of climatic factors on built environment.
Assignment 3	
Assignment Topic and Pedagogy adopted	Heat Transfer Analysis in Building Envelope using Opaque software - This Assignment was carried out using simulation software's and JIGSAW framework
Objective	To experiment the phenomena of heat transfer through different building materials and interpret the relationship between thermal properties and material properties.
Methodology	Students were asked to arrive at a composite wall after some basic data collection about the properties of the individual materials (k-value, R- value). The U-value of different composite building materials is to be calculated and validated in OPAQUE software.
Topics of Discussion	1. k-value, R- value & U- value
Course Outcome Covered	CO3 - Apply the concepts of heat exchange process in buildings and thermal balance equations to analyze heat flow through different building skins

Assignment 4	
Assignment Topic and Pedagogy adopted	Design of shading devices - This Assignment was carried out using manual calculations, simulation software's, scale models and JIGSAW framework
Objective Methodology	To devise a shading device of optimal usage. Shading devices have to be designed for a building to address the e overheated period of the chosen geographical location using the isopleth data derived from assignment #1 To calculate the width and depth of the shading device using HSA & VSA.
Topics of Discussion	1 Solar altitude & azimuth angle. 2.VSA & HSA 3.Sun path diagram 4.Design of shading device for overheated period
Course Outcome Covered	CO4 - Analyze the impact of shading devices on thermal performance of buildings using sun path diagrams and solar shading masks And CO6 - Assess the effects of site, sun & wind on the built environment using physical models and climate analysis software.

decisions on thermal comfort based on the theoretical concepts and results obtained through practical exercises. Finally, the parent groups did the comprehensive analysis of the overall results and impacts through brainstorming sessions and questionnaire surveys and presented the inferences to the whole class. This JIGSAW technique provides a method for students to comprehend and retain material while also improving their collaborative skills (Rambabu, et al.,2018).

4. Results and Discussions

Figure 5 shows the assignment carried out by students using integrated climate data analysis and JIGSAW framework. Figure 5 provides information on how climatic elements affect the design of the space, the layout, and the thermal comfort of users. Each parent group was given a study area and instructed to research the effects of climatic elements such as air temperature, relative humidity, air velocity, radiation, and surface temperature on the area. The spaces were separated into grids of similar size, and the students were given instructions to record the readings in each grid using instruments, analyze its effects on each grid of the given space, and also to record the users' perception using a thermal comfort survey. Then, the groups were reconfigured to create an expert group to investigate the effects of a particular climate factor on various spaces in relation to their location, orientation, fenestrations, etc. The acquired data was analyzed, and each component's relationship to the others as well as their impact on comfort level were investigated. The groups were subsequently instructed to return to the parent group

Fig.5 : Sample presentation Work on Thermal Comfort Analysisdone by students of Group B (2022 Batch)

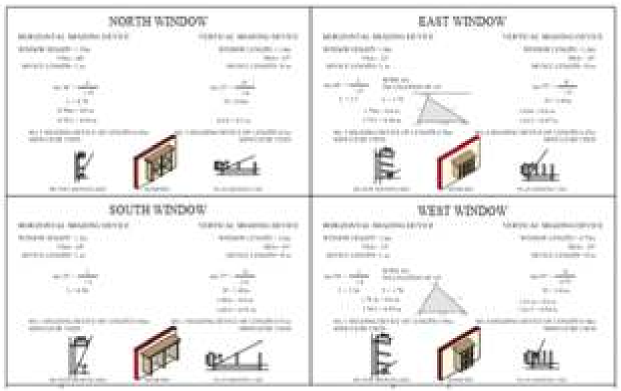

Fig.6 : Sample presentation Work on Design of shading device done by students of Group B (2022 Batch)

in order to determine the ideal design strategies based on the findings. This framework made sure that every student participated equally because they had to give the correct information to the parent group, then the expert group and again to the parent group. This also helped to enhance the communication and presentation skills of all the students.

Information on the design of shading devices and Heat transfer analysis utilizing mathematical calculations and simulation tools, such as Ecotect and OPAQUE software, is provided in Figures 6. For the design of shading device assignment, each parent group student is required to create a shading device for the specified context or climate type with different orientations. Then, the groups were reorganized to form an expert group that would look at the effects of shading in various contexts for a given orientation. Following that, the groups were instructed to rejoin the parent group to assess the effects of shading devices with various orientations in different contexts. The results were verified by the students with the help of online analysis tools. Heat transfer analysis for a building envelope has used the same methodology.

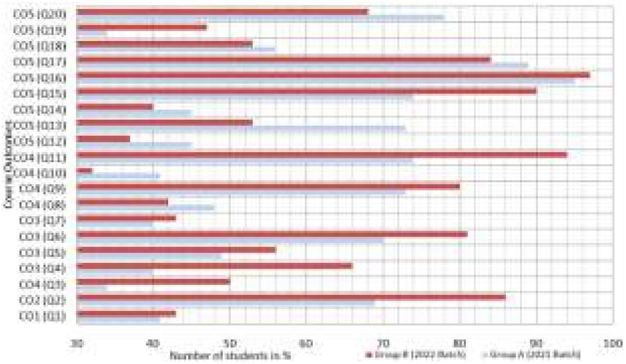

Fig.7 : Comparison of Performance between Group A (2021) and Group B (2022 Batch)

Students carefully examined the thermal characteristics of various building materials using literature research before making their material choices. Composite material was designed based on the U-value calculation done manually and validated by OPAQUE software. The exercises and computations for the assignments were completed manually by the students, and the software was used for the final validation. This gives the students a better understanding about the concepts and methodology as beginners. This enables them in the process of problem solving and troubleshooting in the designing and execution of the projects at various levels and stages.

Figure 7 presents the comparison of average scores of students of Group A, who studied the course through conventional classroom lectures and Group B who studied the course modules through proposed pedagogy.In general Group B students performed well compared to Group A students in all the COs. Expected proficiency level of 80% was achieved for CO1 and CO2 by Group B when compared to Group A. On an average Group B has achieved 77% of proficiency level for CO3, though it is also found Group B has performed better than Group A. Under the CO4 and CO6 category, Group B students performed well compared to Group A. Group B attained 77% of proficiency level for CO4 except for Q10 out of 5 questions. Among the questions addressing CO5, Group B were able to perform well only in three questions. As the questions Q15, Q16 and Q19 were associated with thermal comfort studies which were dealt earlier under assignment 2 of CO1 category, they were able to answer with better clarity. Group A students were able to answer these design strategies related questions in a better way as they started working on design strategies in their third and fourth semester studio subjects. The decline in Group B student's performance on the CO5 questions could be attributed to a lack of discussion sessions and the inability to implement JIGSAW due to insufficient class hours. Despite the fact that a precise deadline was observed for the whole course, the time shortage was caused by late submissions of the beginning exercises.

5. Conclusions

The JIGSAW methodology worked very well and the test results confirm this statement. Based on this study the following conclusions can be drawn:

- JIGSAW is particularly good in helping students to comprehend climate sensitive architecture concepts in a more interactive way.
- The essence of climate study and its implication on the built environment were well received by the students which eventually will contribute to their skill in designing climate responsive buildings.
- The insight about the course they got through these active learning strategies makes the students think about the climatic concepts well in advance during the conceptual stage of their design problems.
- When compared to traditional lecture-based teaching approaches, group activities and peer learning facilitate the accomplishment of COs more effectively.
- The hands-on experiments gave the students the confidence to handle the equipment, a culture of working in groups to achieve certain goals, to expect and provide support to their peers and participate actively in discussions.
- The presentations on their works and the discussion sessions with the faculty develop the confidence and presentation skills.
- The activities enhance the verbal communication skills as well as the visual communications

The JIGSAW methodology, when combined with hands-on experiments, can also be extended to other theory cum practical courses of Architectural Education. The intensity of hands-on activities can be minimized and executed along with JIGSAW for theory subjects also to enhance the attainment of learning outcomes. Though there are many advantages of implementing the jigsaw method it has few drawbacks, like; the technique necessitates some time spent preparing students to learn how to work in groups; additional time is needed while executing the technique in order to form the heterogeneous groups, and in order to implement this strategy successfully, the faculty must make additional preparations. Even though the execution of JIGSAW as an instructional strategy is a strenuous job, careful planning and scheduling would make it more workable. These integrated active learning techniques could bridge the gap between theory and studio subjects. This will allow students to address real-world challenges with a broader perspective and approach, resulting in more long-term solutions.

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ANNEXURE-1
List of questions used for assessment of Group A and Group B

Sl. No	Questions	COs
1.	Which of the following is one of the reasons for urban heat islands?	CO1
2.	Which of the following will affect the microclimate of a building site?	CO2
3.	The solar chart displays the	CO4
4.	The process of heat transfer through a brick wall comes under	CO3
5.	A solid layer of material consists of 0.20m concrete with a thermal conductivity of 2 W/mK. What is the thermal resistance of that layer?	CO3
6.	The reciprocal of thermal conductivity is known as __________	CO3
7.	Provision of large openings facilitates	CO3
8.	Vertical angle at the point of observation between the horizon plane and the line connecting the sun with the observer is	CO4
9.	Under which of the following condition the solar heating due to orientation is maximum	CO4
10.	The data not needed in designing the shading device	CO4
11.	The following determines the design of a shading device	CO4
12.	Identify which is the ideal design strategy of warm humid climate	CO5
13.	Humidity levels within a residence will be high in the following scenario	CO5
14.	This strategy belongs to?	CO5
15.	Does the wind velocity contribute in reducing the ambient air temperature	CO5
16.	Evaporative cooling works best in which of the following climates ___________.	CO5
17.	Bhunga huts in Rajasthan have circular plans because of _________________	CO5
18.	Traditional houses in Kerala have pitched roof as shown	CO5
19.	_____________ climate have sharp diurnal variations	CO5
20.	Warm humid climate prevails	CO5