**Real-Time Thermal Comfort Management in**

**Asia Pacific College:**

**A Non-Invasive Approach Using Thermal Imaging**  
**Thermal Imaging for Clothing Insulation and Metabolic Rates**

A Design Project Proposal Submitted to the School of Engineering  
In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science in Electronics Engineering

Asia Pacific College

by

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September 2024

**ADVISER’S RECOMMENDATION SHEET**

The design project entitled

Thermal Imaging for Clothing Insulation and Metabolic Rates

Real-Time Thermal Comfort Management in Asia Pacific College: A Non-Invasive Approach Using Thermal Imaging

proposed by:

Group B

Geronimo, Keanu Zebadiah P.

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And submitted in partial fulfillment of the requirements of the Methods of Research subject and Bachelor of Science in Electronics Engineering degree, has been pre-approved, examined and recommended for Proposal Defense acceptance and approval.

Engr. Leonardo A. Samaniego, Jr.

Adviser

September 10, 2024

Date

**Approval Sheet**

The design project entitled **Real-Time Thermal Comfort Management in Asia Pacific College: A Non-Invasive Approach Using Thermal Imaging** proposed by:

**Keanu Zebadiah P. Geronimo  
Dorothy Stelrose G. Lorenzo  
Ma. Veronica M. Tirol**

and submitted in partial fulfillment of the requirements of the Bachelor of Science in Electronics Engineering degree, has been examined and recommended for acceptance and approval.

**Engr. Leonardo A. Samaniego, Jr.**  
Design Project Adviser

As title defense panel members, we certify that the design project proposal has been examined and hereby recommended to be accepted as fulfillment of the Methods of Research and design project requirement for the degree **Bachelor of Science in Electronics Engineering**.

|  |  |
| --- | --- |
| **Engr. Stanley Glenn E. Brucal** Committee Chair | **Engr. Luigi Carlo M. De Jesus** Lead Panelist |
| **Engr. Einstein D. Yong** Panel Member 1 | **Engr. Sergio R. Peruda, Jr.** Panel Member 2 |

This design project proposal is hereby approved and accepted by the School of Engineering as partial fulfillment of the requirement for the degree of **Bachelor of Science in Electronics Engineering**.

**Leonardo A. Samaniego, Jr.**

**Program Director, School of Engineering**

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**ABSTRACT**

The abstract is an overview of the project; it is based on information from the Introduction, Statement of the Problem. The information given is usually the basis of many readers as to whether they will read the entire report or not. The abstract is one paragraph of about 200-300 words.

**Keywords:** keyword 1, Proper keyword, common keyword, …, (max) fifth keyword

**Chapter 1**

**Thermal Comfort and Energy Efficiency**

1. **Second Level Heading**
   * 1. **Third level heading**
        + 1. *Fourth Level Heading*

Fifth Level Heading

1. **Introduction**

Comfort significantly affects an individual’s productivity, learning, and overall well-being. One of the key factors influencing comfort in an indoor environment is thermal comfort, which refers to the state of mind where individuals feel satisfied with their thermal environment, and is evaluated through personal subjective assessments [(ANSI/ASHRAE, 2023)](https://ashrae.iwrapper.com/ASHRAE_PREVIEW_ONLY_STANDARDS/STD_55_2023). Thermal comfort can greatly influence how people interact with their environment, particularly in offices, schools, and homes, where optimal comfort can enhance performance and mood.

However, maintaining thermal comfort often comes with the challenge of managing energy consumption. A/C (air condition) systems, which are commonly used to maintain ideal indoor conditions, are energy-intensive and can lead to excessive energy used if not properly managed; the lower the room temperature, the higher the energy consumption [(Sunardi et al., 2020)](https://pubs.aip.org/aip/acp/article-abstract/2248/1/070001/1001262/Effect-of-room-temperature-set-points-on-energy). Hence, thermal comfort is crucial in designing energy-efficient buildings and environments that promote well-being and productivity.

In recent years, the integration of advanced image processing and thermal camera technologies has enabled more accurate assessments of thermal comfort by evaluating key factors like clothing insulation, metabolic rate, and radiant temperature. This paper explores the use of thermal cameras for measuring clothing insulation and metabolic rates and examines how image processing can be used to measure radiant temperature in indoor environments. These technologies aim to improve HVAC systems’ efficiency and occupant comfort.

1. **Background of the Study**

Energy consumption is a critical factor influencing the energy efficiency of educational institutions, especially in classrooms where air conditioning units (ACUs) are essential for maintaining a comfortable indoor climate. At Asia Pacific College (APC), students often experience thermal discomfort after prolonged periods of ACU operation. They frequently feel cold after the first 30 minutes of air conditioning, despite the initial sense of comfort. This discomfort often leads to students adjusting their clothing or seeking alternative means of comfort, such as changing the ACU settings or warming up outside their rooms, which interrupts their focus on academic activities.

A systematic review by [Arsad et al. (2023)](https://link.springer.com/article/10.1007/s11356-023-27089-9), highlights that in environments where thermal comfort is not adequately managed, occupants often make adjustments that can disrupt concentration and productivity. Moreover, [Amoabeng et al. (2023)](https://www.sciencedirect.com/science/article/pii/S2666123322000162) and [Sunardi et al. (2020)](https://pubs.aip.org/aip/acp/article-abstract/2248/1/070001/1001262/Effect-of-room-temperature-set-points-on-energy) show that room temperature setting increments equate to energy savings. In addition, [(Li et al., 2023)](https://link.springer.com/article/10.1007/s10584-023-03500-9) showed that when external temperatures rise, occupants often lower the thermostat set point, which can increase electricity demand. This highlights the importance of gradually adjusting the thermostat in line with room temperature changes would equate to more energy savings and prevent spikes in electricity consumption.

Maintaining thermal comfort in classrooms involves multiple variables such as air temperature, radiant heat, humidity, and occupant-specific factors like clothing insulation and metabolic rate. Conventional approaches rely heavily on subjective feedback or invasive measures. This study aims to develop a system that uses non-invasive thermal imaging and image processing techniques to provide real-time measurements of clothing insulation and metabolic rates through thermal readings, utilizing a thermal camera to continuously monitor these factors and contribute valuable data to thermal management systems for optimizing classroom comfort and promoting energy efficiency within APC.

1. **Objectives**
   * 1. **General objectives**

This study aims to develop a system to quantify clothing insulation and metabolic rates through thermal readings.

* + 1. **Specific objectives**
* To develop a system that is accurate.
  + In terms of gathering insulation data
  + In terms of measuring heat emission
* To develop a system that is efficient.
  + In terms of computation of data
  + In terms of real-time measurement
* To develop a system that is responsive.
  + In terms of computing data
  + In terms of measurement
    1. **Objective metrics**

**Table 1:** Metric and Scale Table

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objectives** | **Definition** | **Metrics** | **Scale** | **Description** |
| Accuracy in terms of gathering insulation data | Measures the deviation of measured insulation values from actual standards, indicating system precision.  (Liu et al., 2022) |  |  |  |
| Accuracy in terms of measuring heat emission | Assesses how accurately the system reads and measures body heat compared to known temperature standards. |  |  |  |
| Efficiency in terms of computation of data | Evaluates how efficiently the system processes and handles large data with minimal CPU and memory usage. |  |  |  |
| Efficiency in terms of real-time measurement | Determines how well the system processes and displays real-time data while minimizing power consumption. |  |  |  |
| Responsiveness in terms of computation of data | Tracks how quickly the system responds to new inputs or changes in thermal conditions. |  |  |  |
| Responsiveness in terms of measurement | Evaluates how fast the system can detect thermal variations. |  |  |  |

* + - * 1. **Accuracy of the System**

The system's accuracy is assessed in two primary areas: measurement precision for the clothe insulation (Clo) data and temperature measurement accuracy for heat emission, such as the metabolic rate (met). With these areas, to compare and evaluate the

*Find the basis for the scale first*

1. Measurement Precision:

2. Temperature Measurement Accuracy

Used accuracy calculations in previous studies (DC^2, Powerpuff, and \*the study they used) CONFUSION MATRIX

What are the parameters to be calculated

1. **Constraints**

* **The study must comply with ANSI/ASHRAE Standard 55-2023: Thermal Environmental Conditions for Human Occupancy Metabolic Rate values.**
* **The study should follow the Republic Act 10173 or the Data Privacy Act of 2012.**
* **Data Accuracy**: The accuracy of thermal imaging in estimating metabolic rates and radiant temperatures is subject to environmental noise and sensor limitations.
* **Distance Sensitivity**: The performance of thermal cameras may degrade with distance, limiting the range of accurate measurements.
* **Lighting Conditions**: Poor lighting may affect the accuracy of image processing techniques used for radiant temperature measurements.
* **Cost Constraints**: High-quality thermal cameras may introduce budgetary constraints, limiting the scalability of the proposed system.

1. **Significance of the Study**
   * 1. **Community**

This study contributes to improving systems of thermal comfort that aims to make energy efficient solutions for the community. This balances the influence of nature and civilization by not using excess energy and still achieving thermal comfort.

* + 1. **Institution**

This provides the institution with insights to help balance the cost of maintaining comfort and enforcing flexible regulations to make tolerances with the student’s activities.

* + 1. **Students**

The students will experience the result of thermal comfort management and will be the source of feedback for what the system will improve upon.

* + 1. **Industry**

The industry can use the system to evaluate and create solutions for their benefit and contribute to a standard in achieving thermal comfort in various conditions.

* + 1. **Future Research**

The study contributes to establishing points of success and failure to support future research, especially in thermal comfort for clothing insulation and metabolic rates.

1. **Scope and Delimitation**
   * 1. **Scope**
     2. **Delimitation**
2. **Conceptual Framework**

**Table 2:** Framework Table

|  |  |  |
| --- | --- | --- |
| **INPUT** | **PROCESS** | **OUTPUT** |
| Thermal Imaging Data:  Clothing Insulation Metabolic Rates  Ambient Temperature  AC Energy Consumption | Data Cleaning  Image Processing: (ThermalYOLO, OpenCV, etc.)  Data Monitoring  Data Analysis  Predictive Analysis | Visualization:  (Temperature, Energy, Comfort, Heat Map)  \*ADD PICTURES |

1. **Definition of Terms**
2. **Definition of Terms**

**ANSI and ASHRAE** -

**Thermal Comfort** -

**Clothing Insulation** -

**Metabolic Rate** -

**Thermal Imaging** –

**Energy Consumption** –

**Occupant** -

**Chapter 2**

**Review of Related Literature and Studies**

1. **Energy Consumption in Relation to Thermal Comfort**

[2.4-2.5]

Energy consumption in buildings, especially for HVAC systems, is a significant global concern, with the International Energy Agency reporting that 30% of the world's energy consumption is related to heating, cooling, lighting, and appliances. In tropical regions, air conditioning systems are vital for maintaining comfortable indoor conditions, but they are also the largest contributors to energy usage in buildings [(Li et al., 2023)](https://doi.org/10.1016/j.energy.2022.125940). [Saba Arif et al. (2023)](https://doi.org/10.1016/j.csite.2022.102534) found that air conditioning accounted for roughly 57% of electricity consumption in buildings in Thailand, with a predicted threefold increase in the future. Educational institutions, which comprise around 17% of non-residential buildings, are growing rapidly and contribute significantly to energy demand due to their large number of students and consistent HVAC use [(Vaisi et al., 2023)](https://doi.org/10.1016/j.enbuild.2022.112689).

This growing energy consumption calls for the integration of energy management systems to optimize HVAC efficiency. [(Balbis-Morejón et al., 2024)](https://www.mdpi.com/2075-5309/14/6/1746) suggest that optimizing these systems can help create a healthy, energy-efficient environment while ensuring thermal comfort, a crucial aspect of indoor environmental quality. According to [(Asim et al., 2022)](https://doi.org/10.3390/ijerph19021016), energy-efficient HVAC systems that consider individual thermal comfort can further reduce energy consumption.

Thermal comfort is a crucial factor of indoor environmental quality, significantly affecting an individual's experience and performance. It is the psychological state in which a person feels satisfied with the thermal conditions of their environment, typically measured through subjective assessment [(ANSI/ASHRAE, 2023)](https://ashrae.iwrapper.com/ASHRAE_PREVIEW_ONLY_STANDARDS/STD_55_2023). [Singh et al. (2019](https://www.sciencedirect.com/science/article/abs/pii/S0378778818336739)) found a strong link between students' academic performance and thermal comfort, with classrooms that maintain ideal temperature levels promoting better focus and engagement. [Jiang et al. (2019)](https://files.eric.ed.gov/fulltext/ED599249.pdf) similarly noted that small changes in room temperature can affect student attention, while [Kükrer and Eskin (2021)](https://www.sciencedirect.com/science/article/abs/pii/S2352710221005556#cebib0010) showed that improved thermal comfort in classrooms and offices directly led to increased productivity. Therefore, achieving a balance between energy consumption and thermal comfort is essential for creating optimal learning environments while minimizing energy use.

1. **Usage of Thermal Cameras for Thermal Comfort**
   * 1. **Calculation (body surface temp for metabolic rate, etc.)**

[2.6]

Thermal cameras play a crucial role in assessing indoor thermal comfort by accurately detecting body surface temperature. According to [(Phuong & Thanh, 2022)](https://ajast.net/data/uploads/92841.pdf), a thermal infrared camera detects infrared waves emitted by objects, converts them into electronic signals, and produces thermal images, allowing it to capture both images and temperature data in light spectrums invisible to the human eye.

* + 1. **Existing Studies (ThermalYOLO, etc)**
    2. **Research Gaps**

1. **Relevance to Present Studies**

**-------------------------------------------------------------------------------------------------------------------------**

1. **Energy Consumption and Efficiency**

Energy consumption in buildings is a significant global concern, accounting for 30 % of total global energy consumption, as said by the International Energy Agency. This energy is mostly spent on heating, cooling, lighting, and powering various appliances, highlighting the HVAC (heating, ventilation, and air conditioning) systems in commercial and institutional buildings like schools. In tropical regions, air conditioning systems are essential for keeping the desired temperature in an environment. Although, these are the largest contributors of energy consumption in buildings [(Li et al., 2023)](https://doi.org/10.1016/j.energy.2022.125940). A case study by [Saba Arif et al. (2023)](https://doi.org/10.1016/j.csite.2022.102534) in Thailand found that roughly 57% of global electricity consumption in buildings is attributable to air conditions, with a threefold increase predicted. Furthermore, educational buildings make up about 17% of all non-residential buildings and are growing rapidly. Schools are filled with thousands of students; demanding high energy consumption [(Vaisi et al., 2023)](https://doi.org/10.1016/j.enbuild.2022.112689).

With such figures, this implies that integrating energy management systems can further optimize air conditioning usage, ensuring more efficient performance in a building. There are alternatives to promote energy efficiency such as optimizing HVAC systems [(Balbis-Morejón et al., 2024)](https://www.mdpi.com/2075-5309/14/6/1746). To provide a healthy, energy efficient, and economical HVAC system, there are parameters to be considered including the individual’s thermal comfort [(Asim et al., 2022)](https://doi.org/10.3390/ijerph19021016).

1. **Importance of Thermal Comfort on Academic Performance**

Thermal comfort is a crucial factor of indoor environmental quality, significantly affecting an individual's experience and performance. It is the psychological state in which a person feels satisfied with the thermal conditions of their environment, typically measured through subjective assessment [(ANSI/ASHRAE, 2023)](https://ashrae.iwrapper.com/ASHRAE_PREVIEW_ONLY_STANDARDS/STD_55_2023). According to [Singh et al. (2019](https://www.sciencedirect.com/science/article/abs/pii/S0378778818336739)), numerous studies done since the 1960s indicate a significant relationship between students' performance and well-being and the thermal environment and air quality in classrooms.

Managing thermal comfort can improve productivity and cognitive performance by decreasing distractions and establishing an environment that is better for learning. Research by [Jiang et al. (2019)](https://files.eric.ed.gov/fulltext/ED599249.pdf) shows that small changes in room temperature significantly affect students' thermal comfort and engagement, with optimal learning occurring when thermal comfort is maintained at moderate levels. A study by [Kükrer and Eskin (2021),](https://www.sciencedirect.com/science/article/pii/S2352710221005556" \l "cebib0010) stated that both students in classrooms and academicians in offices experienced an increase in productivity as thermal comfort levels improved.

1. **Standards for Metabolic Rate and Clothing Insulation**
   * 1. **ASHRAE 55 and ISO 7730**

ASHRAE 55 and ISO 7730 are widely recognized standards published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the International Organization for Standardization (ISO). These standards provide methods for predicting thermal comfort, thermal sensation, and discomfort in indoor environments by considering environmental and personal factors ([Khovalyg et al., 2020)](https://www.sciencedirect.com/science/article/abs/pii/S0378778819314719). Metabolic rate and Clothing insulation are characteristics of the occupant, while air temperature, radiant temperature, humidity, and air temperature are conditions of the thermal environment [(ASHRAE, 2023)](https://ashrae.iwrapper.com/ASHRAE_PREVIEW_ONLY_STANDARDS/STD_55_2023). According to [Khovalyg et al. (2020)](https://www.sciencedirect.com/science/article/abs/pii/S0378778819314719), while ISO 7730 categorizes thermal environments into three distinct levels of comfort, ASHRAE 55 focuses on defining an acceptable thermal environment without employing such categories. These standards aim to enhance thermal comfort through more accurate assessments of both personal and environmental factors, helping to balance occupant comfort with energy efficiency in indoor settings.

1. **Existing Studies on Metabolic Rate and Clothing Insulation**
   * 1. **Assessment of indoor thermal comfort temperature and related behavioural adaptations: a systematic review**
     2. **Machine Learning-Based Automated Thermal Comfort Prediction: Integration of Low-Cost Thermal and Visual Cameras for Higher Accuracy**

(Ashrafi et al., 2022)

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