IARE
INSTITUTE OF
AERONAUTICAL ENGINEERING

# HIGH IMPACT PRACTICES (HIPS)
# CORNERSTONE PROJECTS: THERMAL SYSTEMS ENGINEERING
# INFORMATION PACKET

# 2025 - 2026

INSTITUTE OF AERONAUTICAL ENGINEERING

25 YEARS 2000 2025

I appreciate IARE students who are showing interest in **Intelligent Thermal Systems Engineering (iThermSE)** Project Program at the Institute of Aeronautical Engineering.

**Cornerstone Projects** are comprehensive, application-based projects typically undertaken by students in the second or third year of their academic programs. These projects serve experience that integrates the knowledge, skills, and competencies acquired throughout the curriculum. They are designed for a single semester with a small team upto two students to solve real-world problems through innovative, interdisciplinary

This forward-thinking initiative brings together students, research scholars, and faculty members to form collaborative research groups focused on solving real-world problems at the intersection of thermal engineering and intelligent computation. The **iThermSE** initiative is designed to empower future engineers with the knowledge and skills to design, simulate, optimize, and control advanced thermal systems using AI/ML technologies. This program aims to integrate intelligent algorithms into the entire lifecycle of thermal systems—encompassing heat transfer, thermodynamics, energy systems, fluid dynamics, and environmental sustainability.

The central objective is to promote data-driven and AI-enhanced approaches to thermal engineering challenges, leading to more efficient, reliable, and sustainable thermal technologies across sectors such as aerospace, automotive, power generation, smart buildings, and clean energy. Core Goals of Intelligent Thermal Systems Engineering with Artificial Intelligence (iThermSE) project program are:

- **Predictive Thermal System Behaviour**: Leverage machine learning and data analytics to predict temperature distributions, heat flux, and thermal system performance under varying operating conditions.
- **Optimization of Thermal Performance**: Use AI algorithms (e.g., genetic algorithms, reinforcement learning) to optimize thermal system parameters such as heat exchanger geometry, insulation thickness, flow rates, and cooling paths for maximum efficiency.
- **Intelligent Control and Automation**: Implement AI-driven control systems (e.g., model predictive control, fuzzy logic, RL) for real-time regulation of HVAC, refrigeration, and industrial thermal processes to maintain desired thermal conditions with minimal energy usage.
- **Fault Detection and Diagnostics**: Develop AI-based condition monitoring systems for early detection of failures (e.g., overheating, insulation damage, fouling in heat exchangers) using sensor data, thermal images, or time-series temperature profiles.
- **Digital Twin Development for Thermal Systems**: Create real-time, AI-powered digital replicas of thermal systems for simulation, monitoring, diagnostics, and predictive maintenance, improving decision-making and lifecycle management.
- **Energy Efficiency and Sustainability**: Integrate AI to design and operate thermal systems with reduced energy consumption and carbon footprint—crucial for sustainable buildings, smart cities, and eco-friendly industrial processes.
- **Thermal System Design Innovation**: Enable data-driven, generative, and topology-optimized designs of thermal components (e.g., heat sinks, cooling channels) for compact, lightweight, and high-performance applications.
- **Smart Integration with Renewable Energy Systems**: Enhance the performance of solar thermal collectors, geothermal systems, and hybrid energy setups using AI for predictive control, demand forecasting, and dynamic load balancing.

**The iThermSE project program addresses key SDGs by promoting clean energy, sustainable innovation, climate action, and community well-being.**

| Sustainability Development Goals (SDGs) for the Dept. of ME, IARE | |
|---|---|
| SDG #3 | Ensure healthy lives and promote well-being for all at all ages |
| SDG #4 | Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all |
| SDG #7 | Ensure access to affordable, reliable, sustainable and modern energy for all |
| SDG #8 | Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all |
| SDG #9 | Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation |
| SDG #11 | Make cities and human settlements inclusive, safe, resilient and sustainable |
| SDG #12 | Ensure sustainable consumption and production patterns |
| SDG #13 | Take urgent action to combat climate change and its impacts |

The following research domains are recommended for **HIPs- iThermSE** Projects, and selected students should find the research gap and frame the problem statements from any one of the themes below**.**

1. Smart Thermal Insulation Monitoring System Using IoT and AI *(SDG #7, SDG #9, SDG #11, SDG #12)*
2. Machine Learning-Based Thermal Characterization of Advanced Materials *(SDG #7, SDG #9, SDG #12)*
3. Reinforcement Learning for Optimal Thermal Management in Electric Vehicles *(SDG #7, SDG #9, SDG #11, SDG #13)*
4. Thermal Load Forecasting in Smart Grids using LSTM and Neural Networks *(SDG #7, SDG #9, SDG #11, SDG #13)*
5. AI-Based Predictive Modelling for Heat Exchanger Performance Optimization *(SDG #7, SDG #9, SDG #12, SDG #13)*
6. Digital Twin for Real-Time Monitoring of Heat Transfer Systems *(SDG #7, SDG #9, SDG #12)*
7. Deep Learning for Thermal Image Processing and Diagnostics *(SDG #7, SDG #9, SDG #12)*
8. Smart HVAC System Design Using Predictive Machine Learning *(SDG #7, SDG #9, SDG #11, SDG #13)*
9. Data-Driven Fault Detection in Thermal Power Systems *(SDG #7, SDG #9, SDG #12, SDG #13)*
10. AI-Enhanced Combustion System Design for Emissions Reduction *(SDG #7, SDG #9, SDG #11, SDG #12, SDG #13)*

In order to participate in **iThermSE** Projects, you must formally apply and be accepted by the project coordinator. To proceed, please mail to the project coordinator, Dr. G Himabindu, Assistant Professor, Mechanical Engineering, Email Id: g.himbindu@iare.ac.in. This will bring up all available open positions tagged as **iThermSE** projects. When submitting a project document and an updated résumé, include a statement regarding why you are interested in working with the team to which you are applying. Please note that participation by the **iThermSE** project team requires registration for the accompanying research statement from any of the specified domains. More information will be provided to all selected **iThermSE** project applicants who have been offered a position. If you have any questions about a particular team, please contact the team's faculty mentor(s). We encourage you to contemplate this fascinating new opportunity. We look forward to receiving your application submission.

## Smart Thermal Insulation Monitoring System Using IoT and AI

Dr. Ch Sandeep, Associate Professor & Head, Dept. of ME - Faculty Mentor

## GOALS

This project aims to develop an **AI-based predictive modeling system** for heat exchanger performance optimization, targeting improvements in thermal efficiency, reliability, and operational cost savings. Heat exchangers are critical components in thermal systems used in HVAC, power plants, automotive engines, refrigeration, and chemical processes. However, their performance can degrade over time due to fouling, fluid property changes, or operational inefficiencies.

Traditional modeling techniques rely on complex mathematical correlations and time-consuming CFD simulations. This project leverages AI and machine learning to build fast, accurate, and adaptive models that predict key performance indicators (e.g., heat transfer coefficient, pressure drop, effectiveness) based on real-time or historical operating data.
By enabling real-time performance prediction, fault detection, and optimization recommendations, this project supports the development of smart, self-adaptive heat exchanger systems for industrial and energy-efficient applications.

**Key Goals:**

- Develop ML models to accurately predict heat exchanger performance parameters under varying operating conditions.
- Identify and quantify the effects of fouling, flow maldistribution, and temperature variation using data-driven approaches.
- Enable real-time performance monitoring and early detection of degradation.
- Optimize heat exchanger design and operation based on predictive insights.
- Reduce reliance on complex simulations and manual performance assessments.

## METHODS & TECHNOLOGIES

**Methods (Process & Approach):**

- **Data Acquisition and Feature Engineering**
  Collect data such as inlet/outlet temperatures, flow rates, pressures, fouling resistance, and heat duty from test rigs or industrial systems. Derive relevant features like Reynolds number, Nusselt number, LMTD, and effectiveness.
- **Model Development**
  Train ML models (e.g., Random Forest, Gradient Boosting, Support Vector Regression) for performance prediction. Compare with deep learning models such as ANN, CNN (for spatiotemporal data), and LSTM (for time-series prediction).
- **Validation and Evaluation**
  Use $R^2$ score, MAE, RMSE to assess model accuracy. Perform k-fold cross-validation and sensitivity analysis.
- **Anomaly Detection & Fouling Prediction**
  Train classification or clustering models (e.g., K-means, Isolation Forest) to identify deviations in expected performance due to fouling or malfunctions.

- **Deployment & Visualization**
  Build a cloud-based or local dashboard for visualization of predictions and trend analysis. Deploy model using platforms like Streamlit, Dash, or a microcontroller-based edge AI unit (e.g., NVIDIA Jetson, Raspberry Pi).

**Technologies Used:**

- **AI/ML Frameworks:** TensorFlow, Keras, PyTorch, Scikit-learn, XGBoost
- **Data Processing & Visualization:** Pandas, NumPy, Matplotlib, Plotly, Dash
- **Simulation Tools (for benchmarking):** ANSYS Fluent, COMSOL, MATLAB Simulink
- **IoT & Data Acquisition:** Raspberry Pi/Arduino, NI LabVIEW, RTDs, thermocouples, flow sensors
- **Programming Languages:** Python, MATLAB, C++

## MAJORS & AREAS OF INTEREST

This project is suited for students from Mechanical Engineering, Thermal Engineering, Data Science, Electronics & Communication Engineering, and Computer Science who are interested in AI-driven thermal system optimization, IoT-enabled monitoring, and energy-efficient design. Key focus areas include:

- **AI for Thermal Performance Prediction** – Developing machine learning models (e.g., regression models, neural networks) to predict heat exchanger performance metrics like heat transfer coefficient and pressure drop.
- **Fouling & Degradation Detection** – Using AI/ML-based anomaly detection to identify fouling, flow maldistribution, or temperature variations affecting system efficiency.
- **IoT Sensor Integration** – Deploying temperature, flow, and pressure sensors to collect real-time data for performance monitoring.
- **Data-Driven Heat Exchanger Optimization** – Applying predictive analytics to optimize design parameters, operational settings, and maintenance schedules.
- **Real-Time Fault Diagnosis** – Leveraging AI-based fault detection and predictive maintenance strategies for early identification of performance issues.
- **Digital Twin Development** – Creating virtual models of heat exchangers for real-time simulation, validation, and optimization.
- **Energy-Efficient System Design** – Enhancing the energy efficiency of HVAC, power plant, and industrial heat exchanger systems through data-driven control.
- **Edge AI for On-Site Monitoring** – Implementing lightweight AI models on embedded devices for real-time monitoring and decision-making.
- **Data Engineering & Preprocessing** – Building ETL pipelines for integrating sensor data and historical performance data for AI model training.
- **Visualization & Decision Support Tools** – Developing dashboards and visual analytics tools for real-time performance tracking and optimization recommendations.

## MENTOR CONTACT INFORMATION

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# Smart Thermal Insulation Monitoring System Using IoT and AI

Dr. B Vijaya Krishna, Assistant Professor, Dept. of ME - Faculty Mentor

## GOAL

This project focuses on developing a **Smart Thermal Insulation Monitoring System** that utilizes IoT sensors and Artificial Intelligence to assess and maintain the performance of insulation in real time. Traditional thermal insulation maintenance relies on periodic manual inspections, which can miss early degradation or energy inefficiencies, leading to heat loss, higher operational costs, and safety issues.

By integrating temperature, humidity, and heat flux sensors with intelligent monitoring algorithms, this system aims to continuously assess insulation performance, detect anomalies like moisture ingress or thermal bridging, and predict insulation failure before it occurs. The AI component learns from environmental and operational data to distinguish between normal and faulty insulation behavior.

The goal is to enhance thermal efficiency, ensure energy savings, and enable predictive maintenance for insulated systems across industries such as HVAC, manufacturing, building energy systems, cold chain logistics, and thermal pipelines.

**Key Goals:**

- Develop a smart sensing system to monitor insulation condition in real-time.
- Use AI to detect thermal anomalies, degradation, and performance losses.
- Enable predictive maintenance by forecasting insulation failure trends.
- Minimize energy loss and operational inefficiencies using data-driven insights.
- Support sustainability by extending insulation lifespan and reducing material waste.

## METHODS & TECHNOLOGIES

**Methods (Process & Approach):**

This project integrates sensor networks, data acquisition platforms, and AI algorithms to monitor, learn, and optimize insulation performance. IoT-enabled sensor nodes are deployed to gather multi-point thermal data, which is processed using cloud-based or edge-AI systems for real-time decision-making and visualization.

- **Sensor Deployment & Data Collection**
  Install temperature, heat flux, and humidity sensors on insulation surfaces or embedded layers.
  Use microcontrollers (e.g., Arduino, ESP32) and communication protocols (e.g., MQTT, ZigBee, LoRaWAN) for wireless data transmission.
- **Data Preprocessing & Feature Engineering**
  Clean and normalize data for variations in ambient temperature and seasonal drift. Extract features such as temperature gradients, heat loss rates, and insulation thermal resistance.
- **AI-Powered Anomaly Detection**
  Use supervised and unsupervised ML models (e.g., SVM, k-means clustering, Isolation Forest) to identify abnormal thermal behavior or early signs of failure. Apply time-series analysis (e.g., LSTM networks) for trend forecasting and degradation prediction.
- **Dashboard & Alert System**
  Visualize real-time thermal maps and performance metrics using platforms like Streamlit, Grafana, or custom dashboards. Trigger alerts when insulation performance drops below acceptable thresholds.

- **Maintenance Planning & Reporting**
  Provide actionable insights to facility managers for insulation repair or replacement. Generate predictive maintenance schedules based on AI forecasts.

**Technologies Used:**

- **Sensors & IoT Platforms:** DHT22 (temp/humidity), MLX90614 (IR sensor), MAX6675 (thermocouple), Arduino, ESP32, Raspberry Pi
- **AI/ML Frameworks:** TensorFlow, PyTorch, Scikit-learn, Keras
- **Visualization Tools:** Grafana, Streamlit, ThingSpeak
- **Simulation & Validation:** COMSOL Multiphysics (for thermal modeling), MATLAB
- **Programming Languages:** Python, C/C++, JavaScript (for web dashboards)

## MAJORS & AREAS OF INTEREST

This project is well-suited for AI-powered energy efficiency, predictive maintenance, and IoT-based thermal monitoring systems. Key areas include:

- **IoT-Based Sensing for Thermal Insulation** – Designing and deploying temperature, humidity, and heat flux sensors to continuously monitor insulation performance.
- **AI for Anomaly Detection** – Developing machine learning models to identify thermal bridging, moisture ingress, and insulation degradation.
- **Predictive Maintenance Strategies** – Using AI-driven forecasting to predict insulation failures and schedule proactive maintenance.
- **Energy Efficiency Optimization** – Minimizing energy losses and improving thermal management in HVAC, building energy systems, and industrial pipelines.
- **Data Acquisition & Real-Time Analytics** – Building data pipelines for collecting and processing real-time sensor data for actionable insights.
- **Edge Computing & Embedded AI** – Implementing lightweight AI models on edge devices for real-time anomaly detection in remote or industrial settings.
- **Thermal System Modeling** – Using data-driven and physics-informed models to evaluate insulation performance.
- **Cold Chain and Logistics Applications** – Monitoring insulation in refrigeration and cold storage systems for food and pharmaceutical supply chains.
- **Sustainability & Lifecycle Management** – Extending the lifespan of insulation materials and reducing energy-related emissions through early fault detection.

## MENTOR CONTACT INFORMATION

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## Reinforcement Learning for Optimal Thermal Management in Electric Vehicles

Dr. K China Apparao, Associate Professor, Dept. of ME - Faculty Mentor

### GOAL

This project aims to develop an **AI-based intelligent thermal management system** for electric vehicles (EVs) using Reinforcement Learning (RL). Efficient thermal control of EV components—especially the battery pack, power electronics, and electric motor—is crucial to maintain performance, ensure safety, and extend component lifespan.

Traditional thermal management systems rely on fixed logic, empirical rules, or PID controllers, which are not adaptable to dynamic driving conditions and can result in either undercooling or overcooling, reducing energy efficiency. This project utilizes RL algorithms to learn optimal control policies by interacting with a simulated environment, dynamically adjusting cooling/heating parameters for optimal thermal regulation.

The long-term goal is to reduce energy consumption, maximize battery life, and ensure thermal safety across varying drive cycles and ambient conditions—supporting the development of intelligent, adaptive, and energy-efficient EV systems.

**Key Goals:**

- Use RL to develop adaptive thermal management strategies based on real-time system feedback.
- Optimize temperature regulation of EV battery, motor, and inverter under varying load conditions.
- Minimize energy used by cooling/heating subsystems while maintaining component safety limits.
- Simulate thermal interactions and validate RL agent performance under realistic drive profiles.
- Promote sustainable transportation by enhancing thermal efficiency and EV range.

### METHODS & TECHNOLOGIES

**Methods (Process & Approach):**

- **System Modelling and Simulation Setup**
  Develop thermal and electrical models of battery, inverter, and motor systems using MATLAB Simulink, COMSOL, or Modelica. Simulate EV drive cycles (e.g., WLTP, UDDS) and ambient conditions for realistic thermal profiles.
- **Reinforcement Learning Agent Design**
- Define state space (e.g., temperatures, power demand, ambient temp), action space (cooling fan speed, pump rate, HVAC control), and reward functions (temperature stability, energy savings). Implement algorithms such as DQN (Deep Q-Network), PPO (Proximal Policy Optimization), or DDPG (Deep Deterministic Policy Gradient) for control policy learning.

- **Training and Testing**
  Train the RL agent in a simulated environment to learn optimal thermal strategies. Compare RL performance with traditional control methods in terms of energy use and temperature regulation.
- **Validation & Deployment**
  Integrate RL controller with thermal system simulation. Validate results for dynamic drive scenarios and varying thermal loads. Explore feasibility for deployment on embedded platforms like NVIDIA Jetson or Raspberry Pi.

**Technologies Used**

- **RL Libraries:** OpenAI Gym, Stable-Baselines3, Ray RLlib, TensorFlow Agents
- **Simulation Tools:** MATLAB/Simulink, Modelica, COMSOL Multiphysics
- **Programming Languages:** Python, MATLAB, C++
- **Thermal Modeling:** ANSYS Icepak, MATLAB Battery Blockset, GT-SUITE
- **Data Visualization:** Streamlit, Dash, Matplotlib, Plotly

## MAJORS & AREAS OF INTEREST

This project is well-suited for AI-driven thermal control, electric vehicle systems, and energy-efficient design. Key areas include:

- **Reinforcement Learning for Control Systems** – Developing RL agents (e.g., Deep Q-Networks, PPO) to optimize real-time thermal management strategies for EV components.
- **Battery Thermal Management Systems (BTMS)** – Predicting and regulating battery temperature for safety, longevity, and improved charging/discharging performance.
- **Dynamic EV Powertrain Cooling** – Designing intelligent control for motors, inverters, and power electronics under variable driving and environmental conditions.
- **Simulation-Based Learning** – Using physics-based and data-driven thermal models to train RL agents in a virtual EV environment.
- **Energy Optimization** – Minimizing the energy consumed by HVAC and thermal subsystems while improving vehicle range.
- **Digital Twins of EV Thermal Systems** – Creating real-time virtual replicas for performance monitoring and testing of control policies.
- **Multi-Objective Optimization** – Balancing safety (temperature limits) with energy efficiency and component life extension.
- **Time-Series Forecasting & Prediction** – Leveraging temperature and load prediction to anticipate cooling/heating demands.
- **Integration with Embedded Systems** – Designing lightweight RL controllers for real-time deployment in EV control units.
- **Sustainable Transportation Technologies** – Advancing energy-efficient EV solutions that reduce environmental impact.

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## Thermal Load Forecasting in Smart Grids using LSTM and Neural Networks

Dr. G Sarat Raju, Assistant Professor, Dept. of ME - Faculty Mentor

### GOAL

This project aims to develop an AI-powered predictive system for thermal load forecasting in smart grids using Long Short-Term Memory (LSTM) networks and Deep Neural Networks (DNNs). As energy systems transition towards decentralization and renewables, accurate prediction of thermal energy demand—especially for district heating/cooling, HVAC systems, **and** thermal storage management—is critical to ensuring operational efficiency, grid stability, and energy conservation.

Traditional forecasting techniques struggle with the complex temporal dependencies and nonlinear dynamics associated with thermal loads, especially in the presence of variable weather conditions, occupant behavior, and renewable energy inputs. This project leverages deep learning techniques to learn long-term patterns from historical thermal data, weather data, and control signals to improve forecast accuracy, demand-response planning, and intelligent energy scheduling in smart grids.

**Key Goals:**

- Accurately forecast short-term and long-term thermal loads using LSTM and DNN architectures.
- Enable demand-side management and proactive control of heating/cooling systems.
- Improve energy efficiency and reduce peak thermal load demands in buildings and districts.
- Integrate weather, occupancy, and usage pattern data for context-aware forecasting.
- Support intelligent scheduling of thermal energy storage and smart HVAC systems.

### METHODS & TECHNOLOGIES

**Methods (Process & Approach):**

- **Data Collection & Preprocessing**
  Collect historical thermal load data from smart buildings, HVAC systems, and thermal utilities.
  Incorporate weather data (temperature, humidity, solar radiation) and calendar variables (hour, day, season). Perform normalization, missing data handling, and feature extraction.
- **Deep Learning Model Development**
  Develop LSTM networks to capture temporal dependencies in thermal demand data. Build DNN models to capture nonlinear relationships between input features and target load. Experiment with hybrid LSTM-CNN or attention-based models for performance boost.
- **Model Training and Evaluation**
  Train models using historical datasets and validate using metrics like RMSE, MAPE, and MAE. Perform hyperparameter tuning and regularization to prevent overfitting. Compare deep learning models with baseline techniques like ARIMA, SVR, and Random Forest.

- **Deployment and Visualization**
  Deploy forecasting models on edge devices or cloud platforms for real-time prediction. Build dashboards to visualize predicted vs. actual thermal loads for building operators and grid managers. Enable API-based integration into energy management systems.

**Technologies Used**

- **AI/ML Libraries:** TensorFlow, Keras, PyTorch, Scikit-learn
- **Data Processing Tools:** Pandas, NumPy, OpenWeatherMap API, InfluxDB
- **Forecasting Techniques:** LSTM, DNN, Hybrid CNN-LSTM, Attention Mechanisms
- **Programming Languages:** Python, R, SQL

## MAJORS & AREAS OF INTEREST

This project is well-suited for smart energy management, deep learning, and thermal system optimization. Key areas include:

- **Deep Learning for Energy Forecasting** – Designing and training LSTM and DNN models to predict thermal load patterns across short and long time horizons.
- **Smart Grid and Energy Analytics** – Applying AI for predictive energy management in district heating, HVAC systems, and thermal storage networks.
- **Time-Series Analysis & Forecasting** – Extracting temporal features from historical thermal load, weather, and occupancy data for improved forecasting accuracy.
- **Demand-Side Management (DSM)** – Using predictive insights to optimize heating/cooling schedules and reduce peak demand.
- **Integration of Weather and IoT Data** – Leveraging sensor networks and weather forecasting data for context-aware load prediction.
- **Energy Storage Optimization** – Forecast-driven scheduling of thermal energy storage systems for load balancing and efficiency improvement.
- **Building Energy Management Systems (BEMS)** – Applying AI models to improve HVAC operations and energy conservation in smart buildings.
- **Digital Twin Models for Energy Systems** – Creating virtual models for testing and validating predictive control strategies.
- **Sustainable Energy Systems** – Reducing carbon emissions and energy wastage through accurate and proactive thermal load management.

## MENTOR CONTACT INFORMATION

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## Machine Learning-Based Thermal Characterization of Advanced Materials

**Dr. Ch Sandeep, Associate Professor & Head, Dept. of ME - Faculty Mentor**

### GOAL

This project focuses on applying machine learning (ML) techniques to characterize the thermal properties of advanced materials such as phase change materials (PCMs), aerogels, metal foams, composites, and 2D materials. Traditional material characterization relies heavily on experimental testing, which can be time-consuming, costly, and often limited by scale or instrumentation sensitivity. Moreover, as new materials emerge for use in aerospace, electronics, thermal energy storage, and smart buildings, there is a growing need to predict their thermal behavior quickly and accurately based on structure, composition, and processing conditions.

This project leverages ML models trained on experimental and simulated datasets to estimate properties such as thermal conductivity, heat capacity, thermal diffusivity, and thermal expansion coefficient. By learning from material descriptors and structure–property relationships, ML enables accelerated screening, inverse design, and predictive modeling of thermally functional materials—empowering innovations in thermal management systems.

**Key Goals:**

- Predict thermal properties of advanced materials using supervised ML algorithms.
- Reduce dependency on time- and resource-intensive experimental testing.
- Enable rapid screening of materials for specific thermal applications.
- Discover structure–property correlations to guide material synthesis.
- Support the development of databases and digital twins for thermal materials.

### METHODS & TECHNOLOGIES

**Methods (Process & Approach):**

- **Data Acquisition and Feature Engineering**
  Collect thermal property data from material databases (e.g., Materials Project, MATDB, NIST).
  Extract relevant features: chemical composition, structure type, density, porosity, processing conditions. Apply feature selection, dimensionality reduction (PCA, t-SNE) to enhance model performance.
- **Machine Learning Model Development**
  Train regression models (Random Forest, Support Vector Regression, Gradient Boosting) for property prediction. Use Deep Neural Networks (DNNs) and Graph Neural Networks (GNNs) to capture complex nonlinearities and structural dependencies. Perform hyperparameter tuning and cross-validation for model robustness.
- **Model Evaluation and Interpretation**
  Evaluate models using MAE, RMSE, $R^2$ on unseen datasets. Use SHAP (SHapley Additive exPlanations) or LIME for explainability and feature importance. Compare model predictions with experimental data for validation.
- **Application and Visualization**
  Develop dashboards to visualize property predictions and material selection filters. Integrate ML predictions into simulation tools (e.g., COMSOL, ANSYS) for multiscale analysis. Enable inverse design: suggest material candidates for target thermal performance.

**Technologies Used**

- **ML Libraries:** Scikit-learn, XGBoost, TensorFlow, PyTorch, Matminer, DeepChem
- **Databases:** Materials Project, Citrination, ThermoML, NIST Property Databases
- **Visualization & Interfaces:** Streamlit, Dash, Tableau, Plotly
- **Programming Languages:** Python, MATLAB, R

## MAJORS & AREAS OF INTEREST

This project is well-suited for thermal properties prediction, advanced materials, and AI-driven material discovery. Key areas include:

- **Supervised Machine Learning for Material Properties** – Developing models (e.g., Random Forest, Gradient Boosting, Neural Networks) to predict thermal conductivity, diffusivity, and heat capacity.
- **Data-Driven Materials Engineering** – Creating datasets of experimental and simulated material properties for training ML algorithms.
- **Structure–Property Relationship Modeling** – Extracting features (descriptors) from material microstructures, compositions, and fabrication methods.
- **Thermal Management Applications** – Designing materials for aerospace thermal protection, energy storage (PCMs), and electronics cooling.
- **High-Throughput Material Screening** – Automating the evaluation of material candidates for specific thermal performance requirements.
- **Digital Twins for Material Behavior** – Simulating and predicting thermal responses of advanced materials under real-world conditions.
- **Inverse Material Design** – Using ML to propose new material compositions that achieve target thermal characteristics.
- **Integration of Experimental and Computational Data** – Combining data from DSC, TGA, and molecular dynamics simulations for robust predictions.
- **Nanomaterials and 2D Materials Analysis** – Applying AI to predict thermal transport in graphene, MXenes, and advanced composites.
- **Sustainable Material Innovation** – Identifying eco-friendly, energy-efficient materials with optimized thermal performance.

## MENTOR CONTACT INFORMATION

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## Digital Twin for Real-Time Monitoring of Heat Transfer Systems

**Dr. G Hima Bindu, Assistant Professor, Dept. of ME - Faculty Mentor**

### GOAL

This project focuses on developing a Digital Twin (DT) framework for real-time monitoring, simulation, and optimization of heat transfer systems in industrial and energy applications. Traditional monitoring and control approaches in heat exchangers, cooling loops, and thermal storage systems are often reactive and rely on delayed data acquisition. A Digital Twin bridges this gap by creating a live, dynamic virtual model of a physical heat transfer system, enabling real-time diagnostics, predictive maintenance, anomaly detection, and performance optimization.

By integrating real-time sensor data with physics-based models and AI-driven analytics, the Digital Twin acts as a cyber-physical replica of the system. It continuously updates itself based on incoming data, allowing engineers to make data-informed decisions and forecast thermal behavior under varying operational conditions.

**Key Goals:**

- Develop a real-time digital replica of heat transfer systems for monitoring and control.
- Integrate sensor data with physics-based thermal models for dynamic updates.
- Use AI and machine learning to detect faults, inefficiencies, and thermal anomalies.
- Optimize thermal performance through real-time control and simulation feedback.
- Support predictive maintenance, energy efficiency, and operational sustainability.

### METHODS & TECHNOLOGIES

**Methods (Process & Approach):**

- **System Identification and Physical Modeling**
  Develop governing equations for conduction, convection, and radiation. Model components such as heat exchangers, thermal storage tanks, fluid loops.
- **Sensor Deployment and Data Acquisition**
  Install IoT sensors to monitor temperature, pressure, flow rate, and heat flux. Use microcontrollers (e.g., Arduino, Raspberry Pi) for real-time data transmission.
- **Digital Twin Development**
  Create a virtual model using simulation tools (e.g., MATLAB/Simulink, ANSYS Fluent, COMSOL). Synchronize model parameters with real-time sensor inputs.
- **AI Integration for Fault Prediction and Optimization**
  Train machine learning models (e.g., LSTM, Random Forest, SVM) for pattern recognition and fault detection. Use reinforcement learning for thermal system control and adaptive tuning.
- **User Interface and Visualization**
  Build dashboards for live visualization of temperature profiles, heat flow, efficiency metrics. Include alerts, performance forecasts, and digital control recommendations.

**Technologies Used**

- **Simulation Tools:** MATLAB/Simulink, COMSOL Multiphysics, ANSYS Fluent, Modelica

- **IoT Platforms:** NodeMCU, Raspberry Pi, ESP32 with DHT, PT100, and thermocouple sensors
- **AI/ML Libraries:** TensorFlow, PyTorch, Scikit-learn, Keras
- **Visualization Tools:** Grafana, Power BI, Streamlit, Dash
- **Programming Languages:** Python, MATLAB, C/C++ (for embedded systems)

## MAJORS & AREAS OF INTEREST

This project is well-suited for digital twins, real-time thermal system monitoring, and AI-driven control strategies. Key areas include:

- **Digital Twin Development for Thermal Systems** – Creating real-time, virtual models of heat exchangers, cooling systems, and thermal storage units.
- **Sensor Integration & IoT Data Acquisition** – Deploying temperature, flow rate, and pressure sensors for live data streaming and system feedback.
- **AI & Machine Learning for Thermal Analytics** – Using predictive models for fault detection, anomaly detection, and thermal performance optimization.
- **Physics-Informed Modeling** – Combining CFD-based heat transfer simulations with real-time sensor data to update digital twins dynamically.
- **Predictive Maintenance & Fault Diagnosis** – Forecasting equipment degradation and scheduling proactive maintenance using AI insights.
- **Real-Time Process Optimization** – Implementing data-driven control strategies to improve heat transfer efficiency and reduce energy consumption.
- **Visualization & Control Dashboards** – Building user-friendly dashboards for real-time monitoring, alerts, and simulation-driven decision-making.
- **Cloud & Edge Computing for DTs** – Managing high-frequency thermal data streams and running analytics for industrial-scale systems.
- **Energy-Efficient Thermal Management** – Analyzing operational scenarios to minimize heat loss and enhance energy sustainability.
- **Cyber-Physical Systems & Industry 4.0 Integration** – Enabling smart, connected heat transfer solutions aligned with modern manufacturing and energy systems.

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## Deep Learning for Thermal Image Processing and Diagnostics

Dr. G Sarath Raju, Assistant Professor, Dept. of ME - Faculty Mentor

### GOAL

This project aims to harness the power of deep learning for analyzing thermal images captured through infrared (IR) cameras and thermal sensors to perform advanced diagnostics, fault detection, and thermal behavior characterization. Traditional thermal imaging techniques rely on manual interpretation of heat maps, which can be subjective, error-prone, and inefficient for large-scale or real-time applications.

By integrating Convolutional Neural Networks (CNNs) and other deep learning architectures, the project seeks to automate the extraction of patterns, anomalies, and spatial heat distribution features from thermal images. These AI-powered diagnostics systems can be applied across a wide range of domains—from industrial equipment health monitoring and building thermal audits to biomedical imaging, electrical inspections, and automotive diagnostics.

**Key Goals:**

- Automate the interpretation of thermal images using deep learning models.
- Detect thermal anomalies, faults, and hotspots in real time with high accuracy.
- Enable non-contact, image-based diagnostics across industrial and consumer domains.
- Reduce human error and improve reliability in thermal inspection workflows.
- Support proactive maintenance, safety assurance, and energy efficiency.

### METHODS & TECHNOLOGIES

**Methods (Process & Approach)**

- **Thermal Image Acquisition**
  Capture IR images using FLIR cameras, smartphone-based thermal sensors, or drone-mounted systems. Target surfaces, systems, or materials under different thermal loads.
- **Image Preprocessing and Annotation**
  Apply normalization, noise filtering, and contrast enhancement. Use manual or semi-automated labeling for defect regions, temperature zones, or fault classes.
- **Deep Learning Model Development**
  Use CNNs for classification of image-level faults (e.g., overheating, insulation failure). Apply U-Net or Mask R-CNN for pixel-wise segmentation and localization of thermal features. Employ transfer learning on pre-trained models (e.g., ResNet, MobileNet) for improved accuracy.
- **Model Training and Validation**
  Train models using annotated datasets with cross-validation. Evaluate performance using metrics such as accuracy, IoU, precision, recall, and F1-score.
- **Deployment and Real-Time Diagnostics**
  Integrate trained models into portable apps or embedded systems for field deployment. Enable alerts and reports generation for maintenance teams and safety inspectors.

**Technologies Used**

- **Deep Learning Frameworks:** TensorFlow, PyTorch, Keras, OpenCV
- **Thermal Imaging Tools:** FLIR One, Seek Thermal, DJI Zenmuse XT2 (for aerial imaging)
- **Visualization & UI:** Streamlit, Dash, OpenCV GUI, Flask for web-based tools

- **Programming Languages:** Python, C++ (for deployment), MATLAB (for thermal analysis)

## MAJORS & AREAS OF INTEREST

This project is well-suited for AI-powered thermal imaging, deep learning, and predictive diagnostics. Key areas include:

- **Thermal Image Processing & Computer Vision** – Preprocessing IR images, segmentation, feature extraction, and anomaly detection.
- **Deep Learning Architectures for Imaging** – Implementing CNNs, U-Net, ResNet, and autoencoders for heatmap analysis and fault detection.
- **Industrial Equipment Health Monitoring** – Identifying hotspots, wear, and overheating in mechanical and electrical components.
- **Building & Infrastructure Thermal Audits** – Detecting insulation failures, heat leaks, and energy inefficiencies through IR imaging.
- **Biomedical Thermal Imaging** – Using AI for fever screening, vascular diagnostics, and tissue temperature profiling.
- **Edge AI for Real-Time Diagnostics** – Deploying lightweight CNN models on embedded devices or cameras for on-site inspections.
- **Automotive & Aerospace Thermal Systems** – Monitoring brake systems, engines, and electrical circuits using IR-based diagnostics.
- **Predictive Maintenance & Failure Analysis** – Forecasting potential equipment failures using trends in thermal patterns.
- **Data Annotation & Augmentation Techniques** – Building robust datasets with synthetic heatmaps for training deep learning models.
- **Visualization & Dashboard Development** – Creating interactive heatmap visualization tools with AI-driven insights.

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## Smart HVAC System Design Using Predictive Machine Learning

Dr. K China Apparao, Associate Professor, Dept. of ME - Faculty Mentor

### GOALS

This project aims to develop a **Smart Heating, Ventilation, and Air Conditioning (HVAC)** system empowered by predictive machine learning models for enhanced energy efficiency, occupant comfort, and autonomous control. Conventional HVAC systems often operate on static schedules or fixed rule-based logic, leading to energy waste, poor responsiveness to environmental changes, and high operational costs.

By integrating real-time environmental sensing with predictive modeling and optimization algorithms, the project envisions a dynamic HVAC system that adapts to usage patterns, weather forecasts, occupancy trends, and thermal loads. Machine learning enables anticipatory control strategies that minimize energy consumption while maintaining thermal comfort across different building zones.

**Key Goals:**

- Develop predictive models for HVAC load forecasting and energy consumption.
- Enable real-time, adaptive HVAC control using ML-driven decision systems.
- Optimize energy use while maximizing thermal comfort and air quality.
- Integrate IoT sensors, cloud platforms, and AI to create intelligent building environments.
- Support sustainable and smart building design initiatives.

### METHODS & TECHNOLOGIES

**Methods (Process & Approach):**

- **Data Acquisition & Environment Profiling**
  Collect indoor and outdoor parameters: temperature, humidity, $CO_2$ levels, occupancy, solar radiation, etc. Use smart thermostats, occupancy sensors, and building management systems (BMS) for real-time data streams.
- **Predictive Modeling for Thermal Load Forecasting**
  Train regression models (e.g., Random Forest, Gradient Boosting, LSTM) to predict future heating/cooling loads. Incorporate time-of-day, day-of-week, weather forecast, and occupancy trends into model features.
- **Comfort and Energy Optimization**
  Define thermal comfort zones using standards (e.g., ASHRAE 55). Use ML classifiers and optimization algorithms to balance comfort vs energy trade-offs.
- **Smart Control System Integration**
  Develop control logic that uses model predictions to adjust HVAC operation in real time. Integrate predictive control with building automation platforms or IoT middleware.
- **Validation and Continuous Learning**
  Use historical and real-time data to validate model accuracy. Enable self-learning capabilities to adapt to seasonal changes and evolving usage patterns.

**Technologies & Tools**

- **Machine Learning Libraries:** Scikit-learn, XGBoost, LightGBM, TensorFlow, Keras, Statsmodels
- **IoT Sensors & Hardware:** DHT22/AM2302 (temp/humidity), PIR sensors, air quality sensors, smart meters

- **HVAC Simulators & Tools:** EnergyPlus, OpenStudio, TRNSYS, MATLAB Simulink
- **Programming Languages:** Python, JavaScript, MATLAB, C++

## MAJORS & AREAS OF INTEREST

This project is well-suited for smart building technologies, energy optimization, and predictive machine learning applications. Key areas include:

- **HVAC System Design & Thermal Engineering** – Understanding heating/cooling loads, ventilation dynamics, and energy efficiency principles.
- **Predictive Machine Learning Models** – Developing regression models, time-series forecasting (LSTM, ARIMA), and reinforcement learning for HVAC control.
- **IoT-Enabled Smart Building Systems** – Integrating temperature, humidity, $CO_2$, and occupancy sensors with cloud-based control platforms.
- **Energy Optimization & Demand-Side Management** – Reducing energy waste while maintaining comfort by predicting peak loads and adjusting operations.
- **Thermal Comfort & Air Quality Modeling** – Balancing indoor climate conditions with human comfort indices (PMV/PPD models).
- **Real-Time Data Analytics & Control Systems** – Implementing adaptive control strategies that respond dynamically to changing environmental conditions.
- **Weather Forecasting Integration** – Using external data (temperature, solar gain, humidity) to adjust HVAC operation proactively.
- **Digital Twin for Smart Buildings** – Creating virtual HVAC models for testing energy-saving strategies before real-world deployment.
- **Sustainable Building Design** – Supporting green building initiatives (LEED, BREEAM) through efficient energy use.
- **Cloud & Edge Computing for Automation** – Deploying predictive algorithms on cloud platforms or local controllers for real-time HVAC adjustments.

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## Data-Driven Fault Detection in Thermal Power Systems

**Dr. B Vijaya Krishna, Assistant Professor, Dept. of ME - Faculty Mentor**

### GOALS

This project aims to develop an **AI-enabled fault detection and diagnostics framework** for thermal power systems using real-time operational data and historical logs. Traditional condition monitoring techniques in power plants rely heavily on manual inspections, threshold-based alarms, or model-based estimations, which are often delayed, inaccurate, or inflexible to operational variability.

By integrating machine learning, sensor fusion, and anomaly detection algorithms, the project seeks to proactively identify potential faults such as overheating, fouling, leakage, or turbine blade damage before they escalate into critical failures. This data-driven approach enhances system reliability, predictive maintenance, and plant safety, while minimizing unplanned downtime and maintenance costs.

**Key Goals:**

- Build accurate predictive models to detect faults and anomalies in thermal power systems.
- Minimize downtime and improve plant safety via early fault identification.
- Use AI for root cause analysis and fault classification in components like boilers, turbines, heat exchangers, and pumps.
- Integrate fault detection with SCADA systems for automated alerts and maintenance recommendations.
- Support sustainable and cost-effective plant operation with intelligent monitoring.

### METHODS & TECHNOLOGIES

**Methods (Process & Approach):**

- **Data Acquisition & Preprocessing**
  Collect real-time and historical sensor data: temperature, pressure, flow rate, vibration, and acoustic signals. Perform data cleaning, normalization, and time-series alignment.
- **Feature Engineering**
  Extract key indicators: rate of change, statistical metrics (mean, variance), spectral features (FFT, wavelets). Apply dimensionality reduction (e.g., PCA, t-SNE) for multivariate signal simplification.
- **Fault Detection & Classification**
  Train supervised classifiers (Random Forest, SVM, XGBoost) for known fault types. Use unsupervised models (Autoencoders, Isolation Forest, DBSCAN) for novel or incipient fault detection. Implement sequence models (LSTM, GRU) for detecting temporal patterns and time-dependent anomalies.
- **Root Cause Analysis & Maintenance Insights**
  Analyze correlation among variables using SHAP or LIME for explainable AI diagnostics. Suggest probable root causes and maintenance actions based on historical fault cases.

- **Integration & Visualization**
  Deploy ML models on edge devices or integrate with SCADA/BMS platforms for real-time alerts. Provide operator dashboards for fault heatmaps, predictive alerts, and maintenance planning.

**Technologies & Tools**

- **AI/ML Libraries:** Scikit-learn, TensorFlow, PyTorch, PyCaret, TSFEL (Time-Series Feature Extraction)
- **Data Processing Tools:** Pandas, NumPy, SciPy, Dask, Apache Kafka (for real-time streaming)
- **Industrial Systems:** SCADA, DCS, OPC-UA middleware
- **Programming Languages:** Python, R, MATLAB, C++

## MAJORS & AREAS OF INTEREST

This project is well-suited for power plant systems, predictive maintenance, and AI-driven fault diagnostics. Key areas include:

- **Thermal Power Plant Operations** – Understanding boilers, turbines, condensers, pumps, and heat exchangers.
- **Condition Monitoring & Predictive Maintenance** – Developing techniques to detect early signs of equipment wear, fouling, or failure.
- **Machine Learning & Anomaly Detection** – Implementing supervised/unsupervised learning, classification, and clustering algorithms for fault prediction.
- **Sensor Fusion & SCADA Integration** – Combining multi-sensor data (temperature, pressure, vibration) with real-time monitoring systems.
- **Data-Driven Root Cause Analysis** – Identifying critical failure points and determining contributing factors through historical trend analysis.
- **Signal Processing & Feature Extraction** – Analyzing vibration signals, temperature profiles, and flow parameters for fault signatures.
- **Time-Series Analysis** – Leveraging LSTM networks, ARIMA models, and forecasting methods for operational anomaly detection.
- **Energy Efficiency & Reliability Engineering** – Minimizing energy losses and downtime through proactive fault prevention.
- **Digital Twins of Power Systems** – Simulating and validating fault detection strategies in virtual power plant environments.
- **Industrial AI Applications** – Using deep learning, random forests, and ensemble models for predictive diagnostics.

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## AI-Enhanced Combustion System Design for Emissions Reduction

Dr. G Hima Bindu, Assistant Professor, Dept. of ME - Faculty Mentor

### GOALS

This project focuses on leveraging Artificial Intelligence to optimize the design and operation of combustion systems with the primary goal of reducing harmful emissions such as $NO_x$, CO, and unburned hydrocarbons. Traditional combustion design relies on empirical modeling, rule-based tuning, and CFD simulations, which are often time-consuming and limited in adaptability to varying fuel types or real-world conditions.

The objective is to create AI-augmented combustion models that integrate design simulation data, sensor feedback, and advanced optimization algorithms to guide the design of low-emission burners, furnaces, engines, and boilers. These models help in adaptive flame control, mixture optimization, and real-time emissions prediction, thereby accelerating the development of cleaner and more efficient thermal energy systems.

**Key Goals:**

- Use AI to predict and minimize emission levels based on fuel type, geometry, and operating conditions.
- Enhance combustion efficiency through data-driven air-fuel ratio optimization and flame stability analysis.
- Integrate AI with CFD tools to accelerate the iterative design of combustion chambers and burners.
- Enable real-time tuning of combustion parameters for dynamic load and fuel conditions.
- Support decarbonization goals by enabling the use of alternative fuels with intelligent combustion strategies.

### METHODS & TECHNOLOGIES

**Methods (Process & Approach)**

- **Combustion System Modeling**
  Develop baseline CFD models (ANSYS Fluent, OpenFOAM) of the combustion chamber under different geometries and boundary conditions. Simulate flame temperature, emissions, and turbulence profiles.
- **Dataset Generation & Feature Extraction**
  Generate synthetic datasets from simulation and experimental runs (fuel type, injection velocity, excess air, swirl intensity, etc.). Extract features such as flame length, peak temperature, and pollutant formation rates.
- **AI-Based Prediction & Optimization**
  Train regression models (XGBoost, ANN) to predict $NO_x$/CO emissions. Use deep neural networks and surrogate models to emulate CFD results for fast performance estimation. Apply reinforcement learning for adaptive control of fuel injection, airflow, and burner angle.
- **Design Space Exploration**
  Use genetic algorithms or Bayesian optimization to explore geometric and operational design spaces for emission minimization and efficiency improvement.
- **Real-Time Monitoring & Control Integration**
  Integrate AI models into combustion control systems (e.g., PID, fuzzy control) for real-time emissions minimization under dynamic loads.

**Technologies & Tools**

- **CFD & Combustion Simulation:** ANSYS Fluent, COMSOL Multiphysics, Open-FOAM
- **AI/ML Libraries:** TensorFlow, PyTorch, Scikit-learn, Keras, DEAP (for evolutionary algorithms)
- **Optimization Platforms:** MATLAB Optimization Toolbox, GPyOpt, Optuna
- **Programming Languages:** Python, MATLAB, C++, Fortran (legacy combustion solvers)

## MAJORS & AREAS OF INTEREST

This project is well-suited for clean energy technologies, AI-driven combustion optimization, and emission reduction strategies. Key areas include:

- **Combustion and Thermal Engineering** – Understanding combustion physics, heat transfer, and flame dynamics.
- **Emission Control and Environmental Engineering** – Strategies for reducing $NO_x$, CO, unburned hydrocarbons, and particulate matter.
- **AI and Machine Learning for Combustion** – Predictive modeling, regression, and optimization for emission reduction and efficiency.
- **Computational Fluid Dynamics (CFD)** – Simulating combustion chambers, burners, and flame characteristics using AI-augmented models.
- **Sensor Integration and Real-Time Control** – Using IoT-based sensors for flame monitoring, emission tracking, and adaptive control.
- **Air-Fuel Mixture Optimization** – Data-driven tuning of stoichiometry and equivalence ratios for complete combustion.
- **Alternative and Sustainable Fuels** – Adapting combustion systems for biofuels, hydrogen, and synthetic fuels with AI-based performance prediction.
- **Reinforcement Learning for Process Control** – Dynamic tuning of combustion parameters for fluctuating loads and fuel variations.
- **Digital Twin for Combustion Systems** – Creating virtual replicas for real-time emissions prediction and operational optimization.
- **Energy Efficiency and Decarbonization** – Designing low-carbon combustion systems aligned with global sustainability and clean energy goals.

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