KBTU KAZAKH-BRITISH TECHNICAL UNIVERSITY

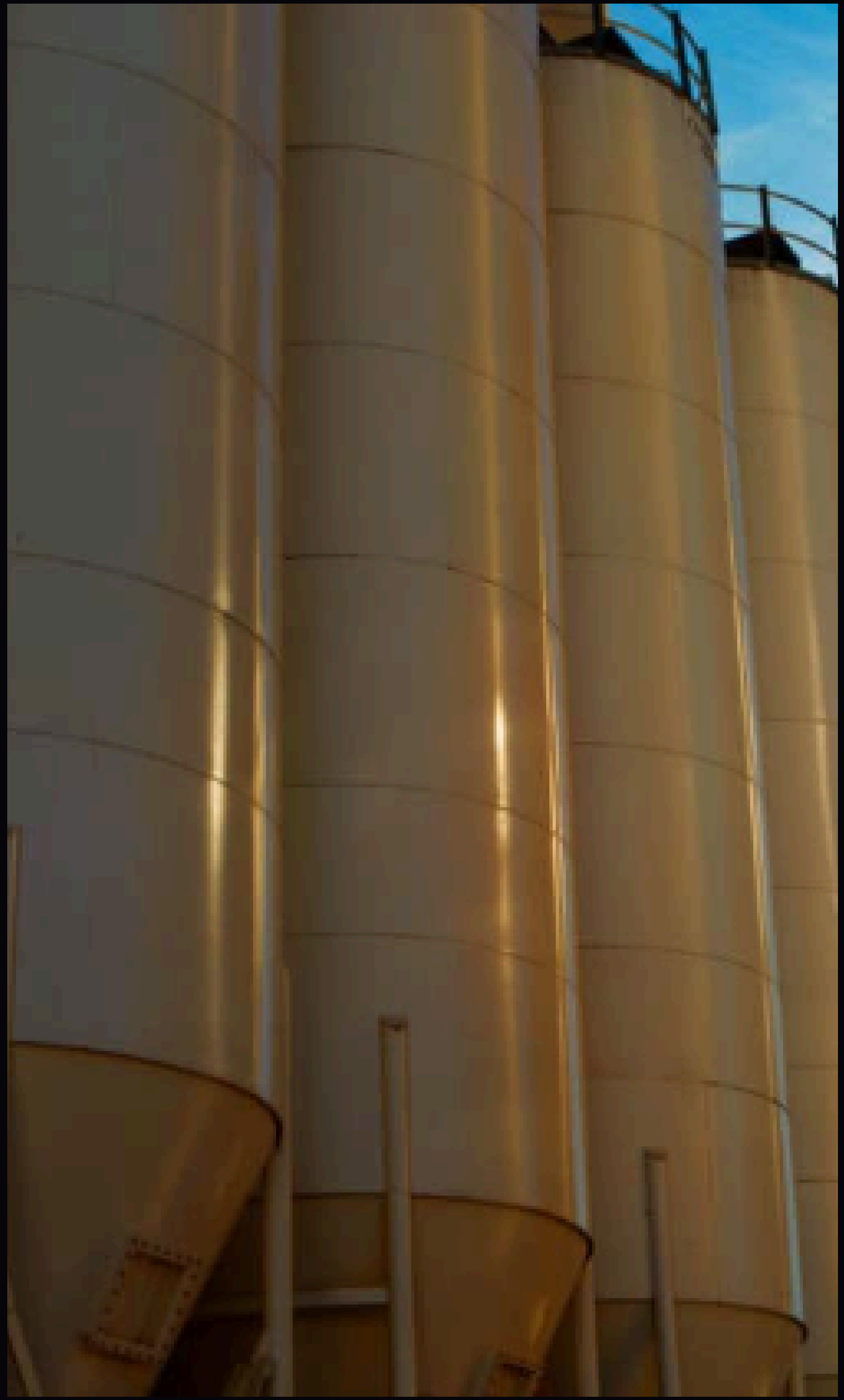
By Collins Masimba

Checked by Prof. Zarina Samigulina

DEVELOPMENT OF AN AUTOMATED CLIMATE CONTROL SYSTEM FOR A GRAIN STORAGE FACILITY BASED ON THE SMART CITY CONCEPT

INTRODUCTION

- Grain storage vital for economies and food security; losses lead to inefficiencies and increased human effort
- **Objective**: Automate HVAC using PLC, SCADA, and fuzzy PID to maintain optimal temperature/humidity
- Prevents spoilage from microorganisms; integrates with smart city for real-time monitoring
- **Control object:** Heat exchanger for temperature regulation
- Key outcomes: <1% grain loss, 20-30% energy savings, scalable for urban resilience



PROBLEM STATEMENT

- Global grain losses cause food shortages amid population growth and climate challenges
- Causes: Mold, insects leading to poisoning, economic losses, and 6% of greenhouse emissions (FAO data)
- Undernourishment rose in 2020 pre-COVID; monitoring essential to prevent rejection of grain lots
- Solution: PLC/SCADA with fuzzy logic for detecting unfavorable conditions (e.g., high humidity)
- Challenges: Implementing fuzzy logic in PLC due to memory issues; volume-based leak detection used

Collins

PARAMETER

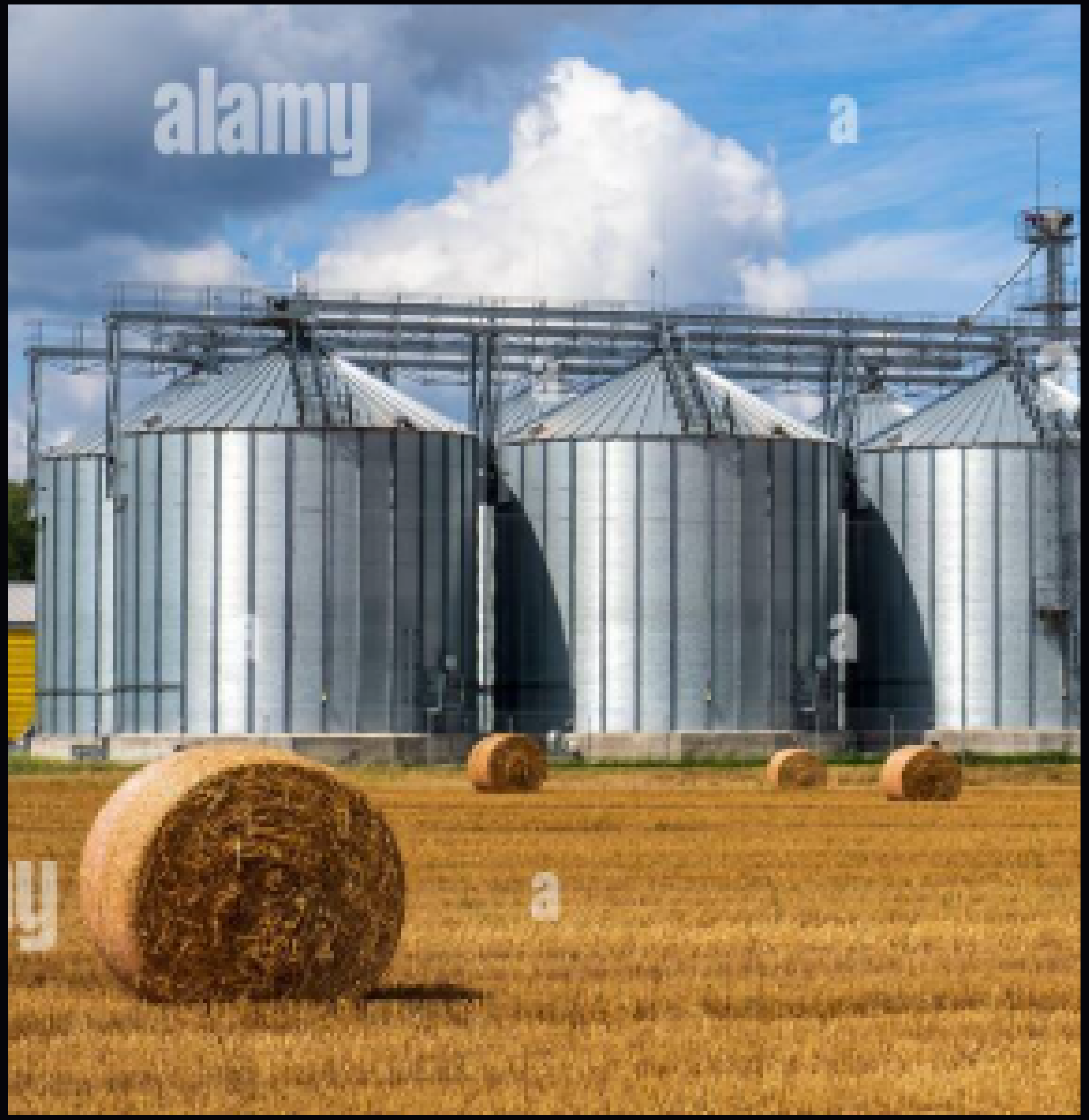
No	Parameter	Value	Unit	Tolerance	Description	I/O
1	Temperature	15-18	°C	±0.5	Air temp inside silo;	Input
2	Relative Humidity	60-65	%	±2	Moisture level; prevents	Input
3	Coolant Flow Rate	0.5-3.0	m³/h	Dynamic (4-20 mA)	Chilled water flow;	Output
4	Air Flow Rate	2590	m³/h	VSD modulation	Conditioned air volume	Output

- Real-time monitoring of temperature/moisture in silos using cable-based sensors (thermistors, thermocouples)
- Core component: Shell-and-tube heat exchanger for cooling/dehumidification
- Process flow: Initialization, temperature reading, PLC feedback, alarms for deviations

TECHNOLOGICAL PROCESS

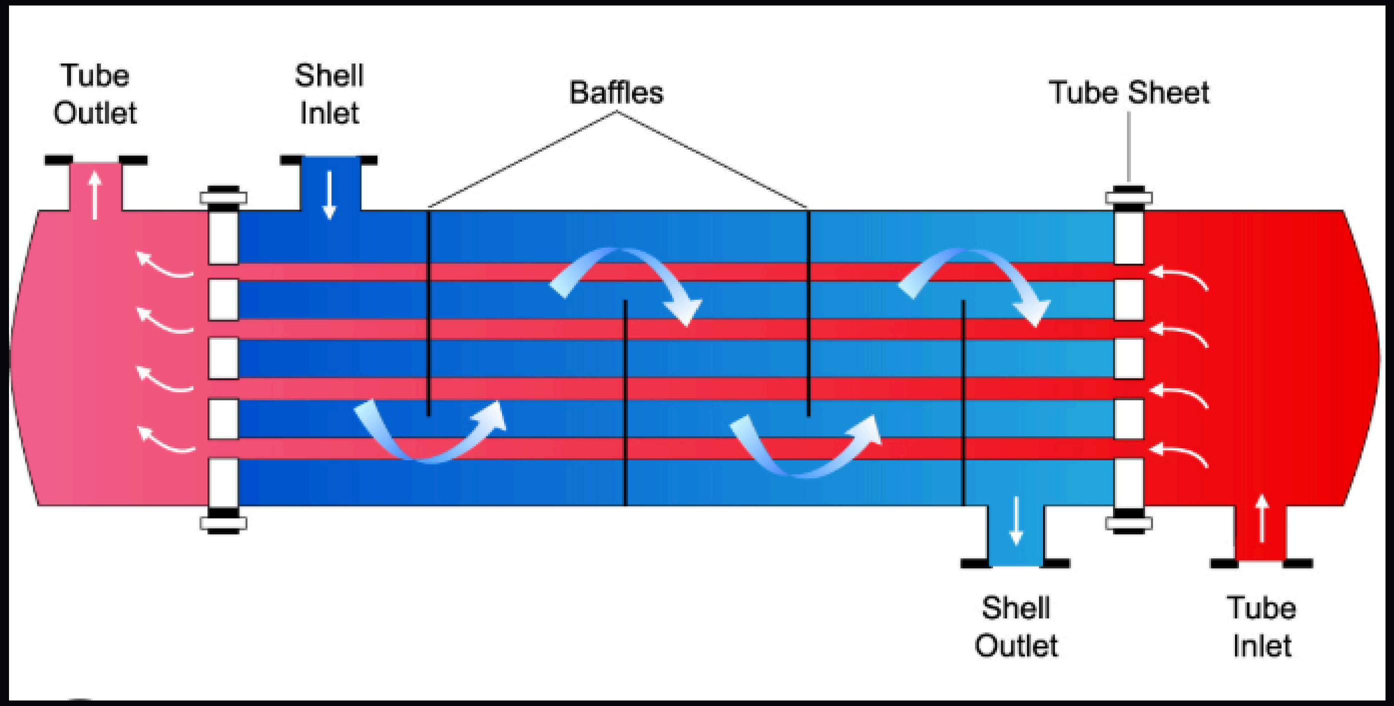
Collins

CONTROL OBJECT



- Chosen object: Shell-and-tube heat exchanger with air conditioner for regulation
- Structural scheme: Black box model with inputs (heating fluid temp) and outputs (final temp)
- Variables: Temperature (15–18°C, ±0.5), RH (60–65%, ±2%), flow rates; SI units with tolerances
- P&ID diagram: Sensors connected via RF to PLC; alarms for high/low priority deviations
- Setup: Extract warm air, cool via exchanger, recirculate for efficiency

Shell and Tube Heat Exchanger



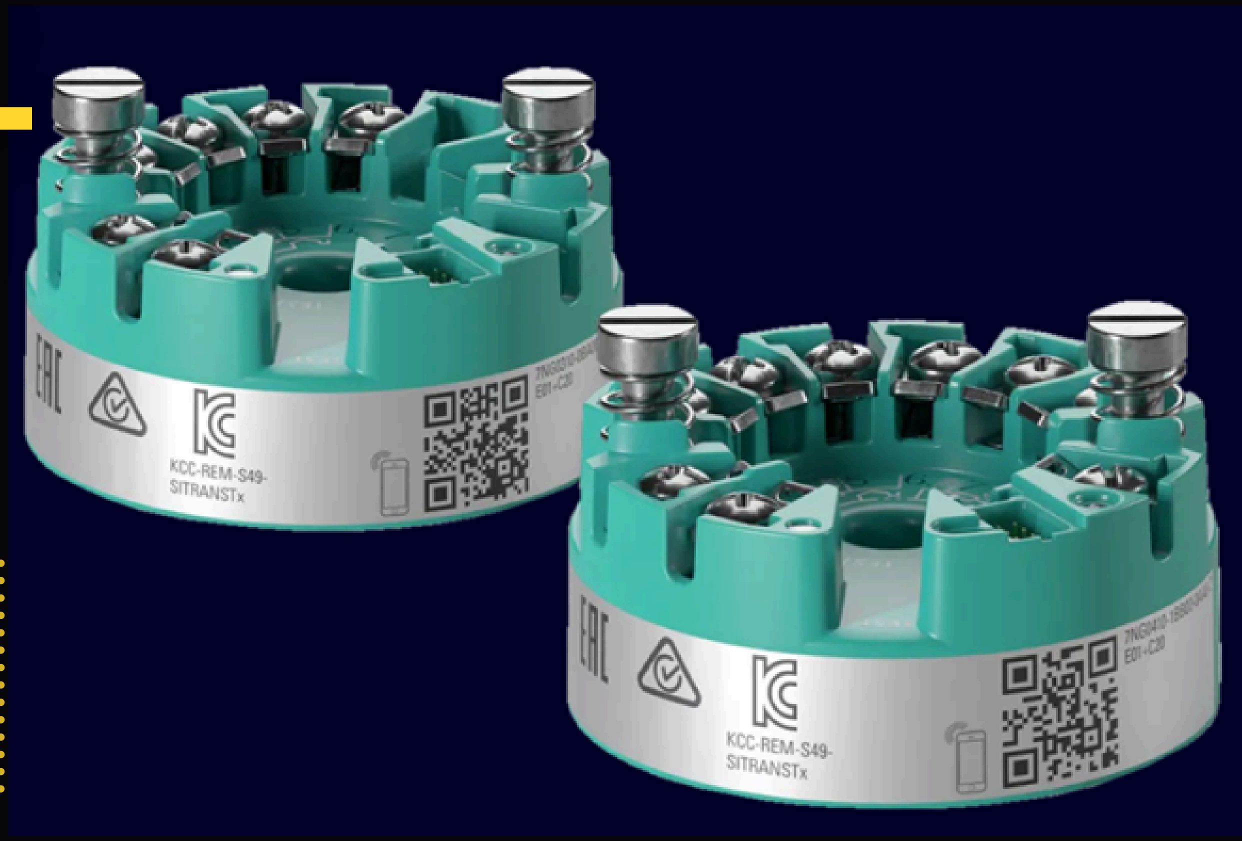
Collins

MATHEMATICAL MODEL

$$G_p(s) = \left.\frac{T(s)}{T_c(s)}\right|_{T_a(s)=0} = \frac{K_2}{\tau_s + 1}$$

Transfer function from the heat-exchanger fluid temperature to the grain temperature which will be the proposed control function will be:From the transfer functions 3.4 and 3.3 is the fraction of the total heat transfer that occurs through the walls to the ambient while is the fraction of the total heat transfer that occurs through the heat exchanger. In the research project its assumed that K2 = 1

TECHNICAL EQUIPMENT

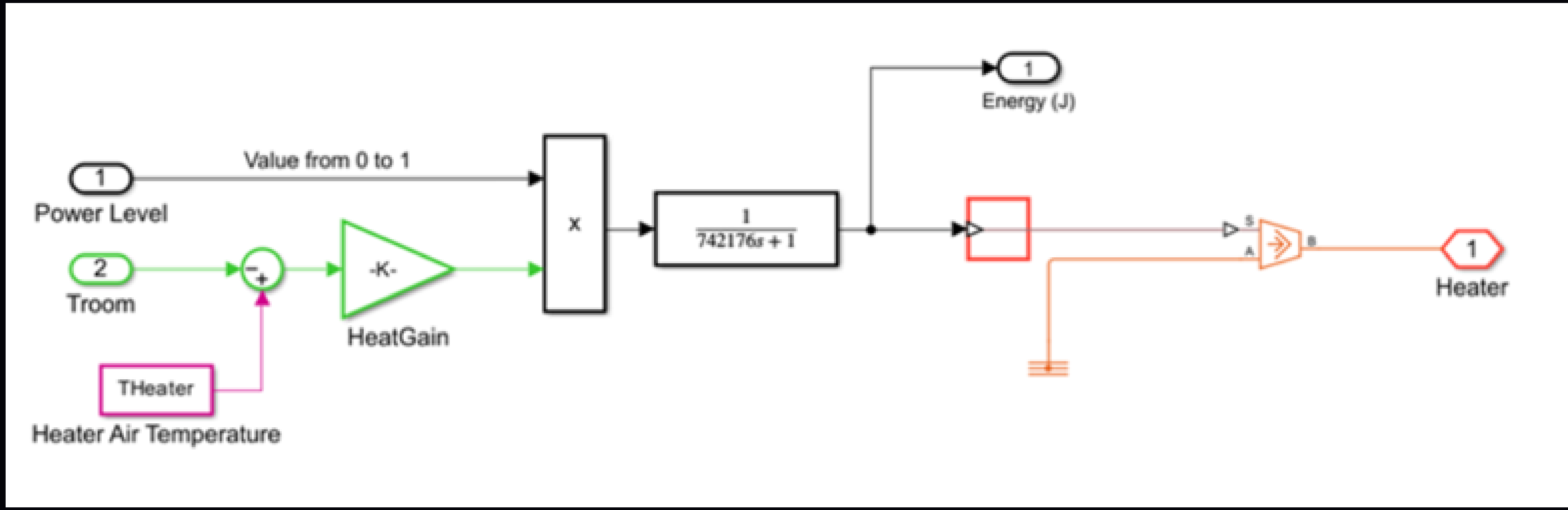


01	**SITRANS TH420/TH320**	MATLAB
02	**SIMATIC S7-1200 CPU 1215C**	TIA PORTAL
03	**Communication Systems**	PLCSIM

PROGRAM REALIZATION

MATLAB

SIMULINK MODEL

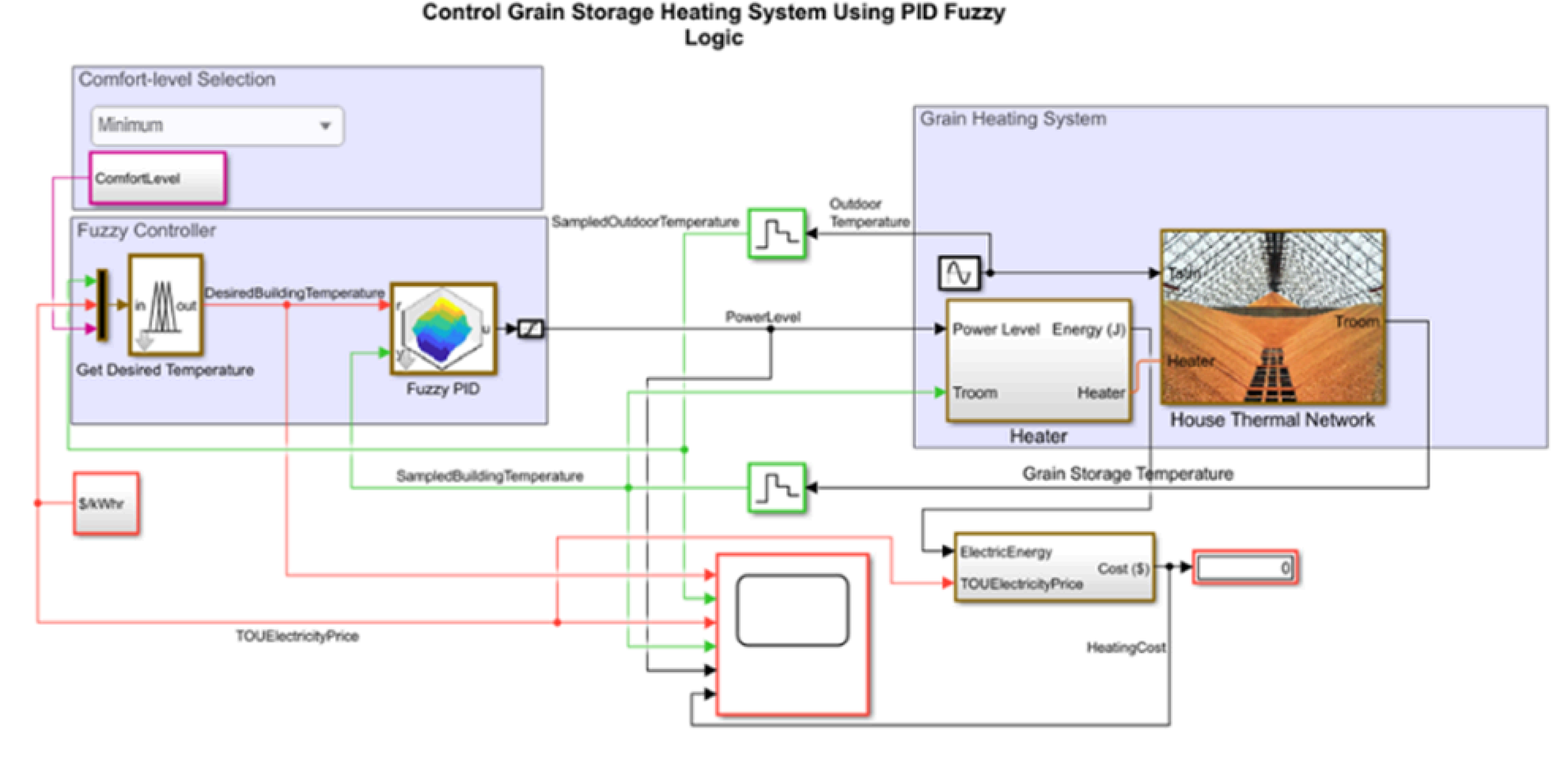


Aerodynamics studies how air interacts with moving objects, influencing lift, drag, and stability. This knowledge is crucial for designing efficient and safe aerospace vehicles.

PROGRAM REALIZATION

MATLAB

SIMULINK MODEL

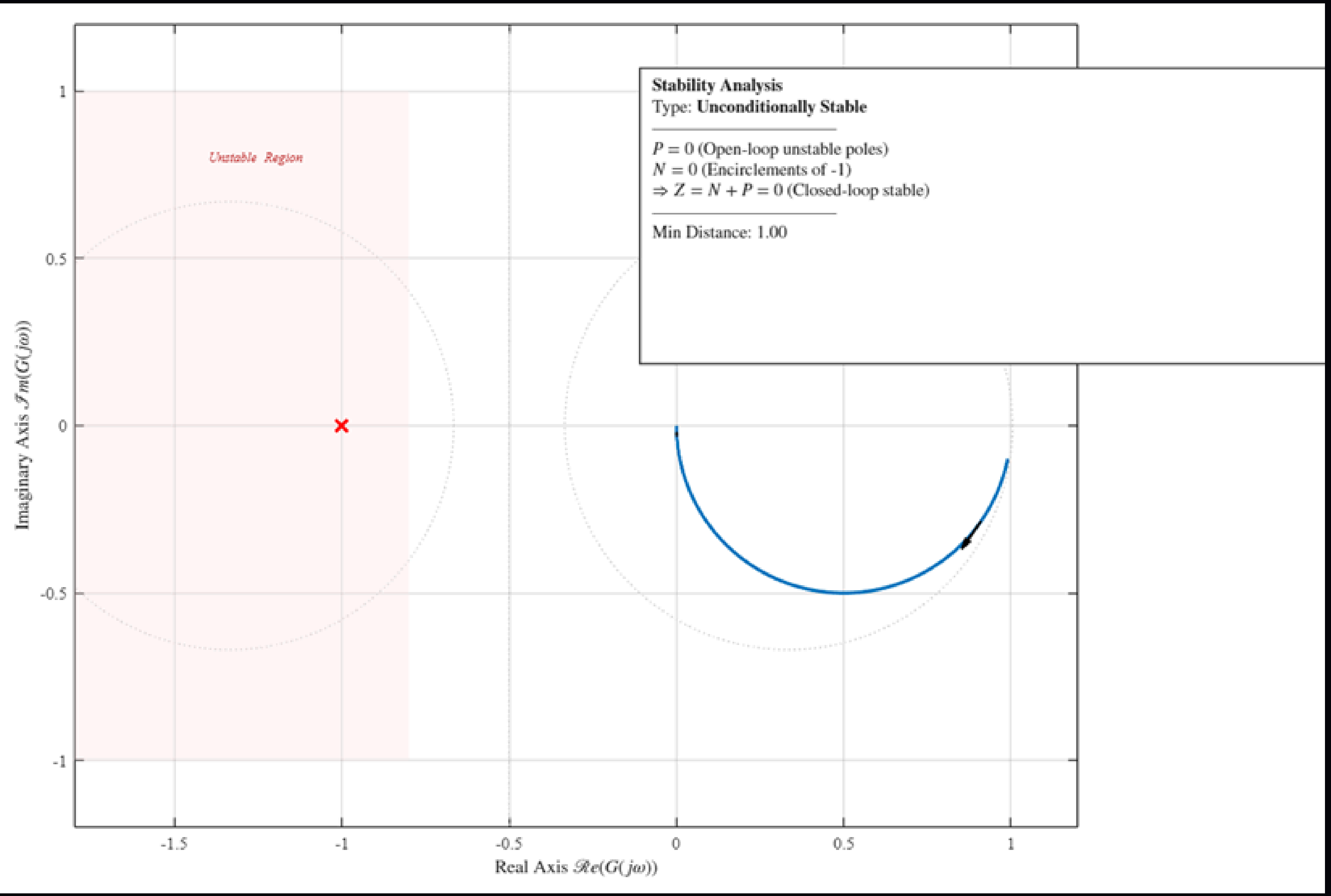


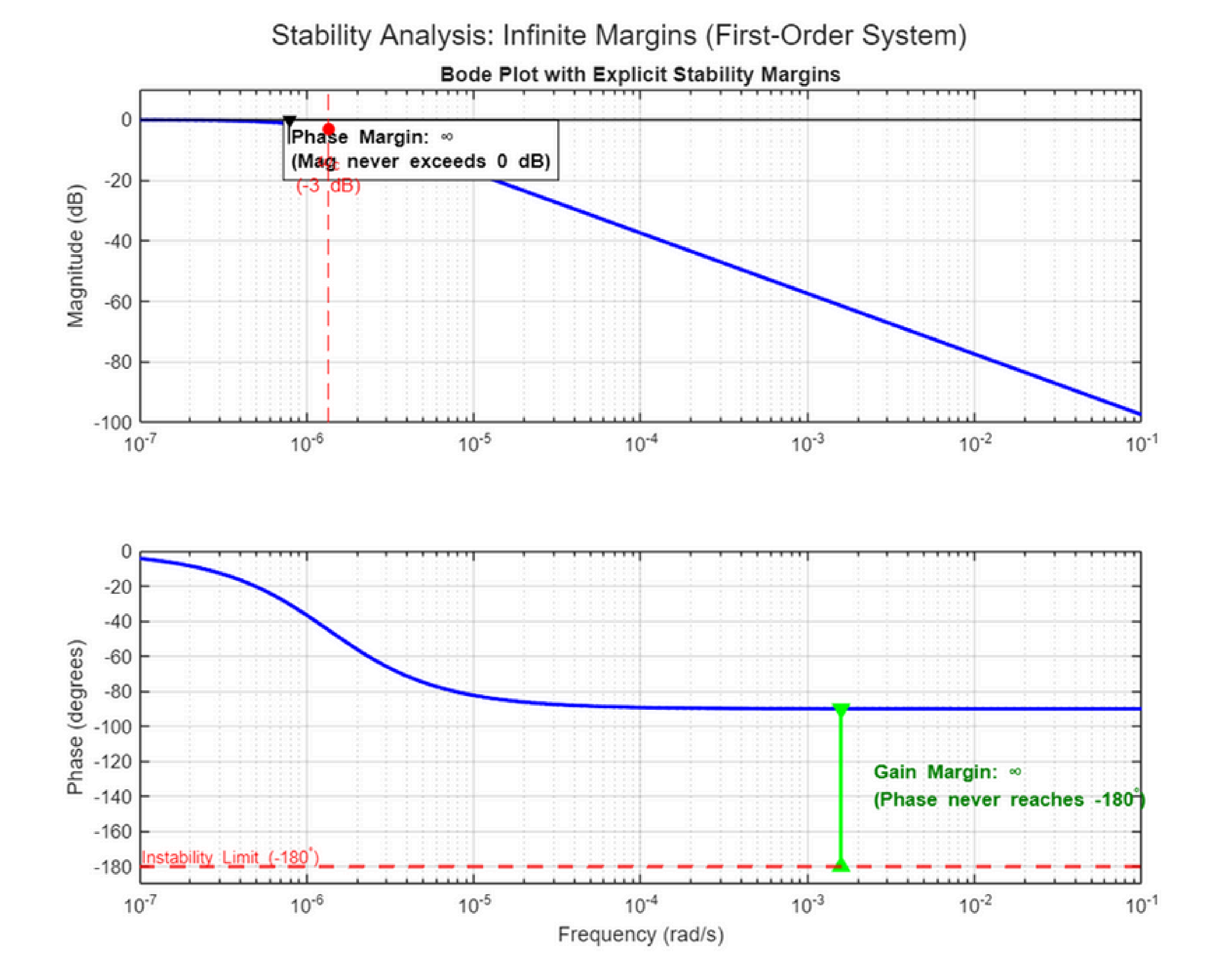
– The presented Simulink model implements a sophisticated, energy-cost-aware thermal control system for a building equipped with electric heating and a thermal storage medium (grain), representing a realistic low-cost seasonal storage concept. The architecture adopts a two-layer hierarchical fuzzy logic control strategy, which elegantly separates high-level energy-management decisions from low-level temperature regulation.

PROGRAM REALIZATION

MATLAB

STABILITY ANALYSIS





The stability of the closed-loop system, based on the loop transfer function, is determined by applying the Nyquist Stability Criterion from Appendix D. This criterion requires that the number of counterclockwise encirclements of the critical point (-1, 0) by the Nyquist plot must equal the number of unstable (Right Half-Plane) poles (P) of the open-loop transfer function.

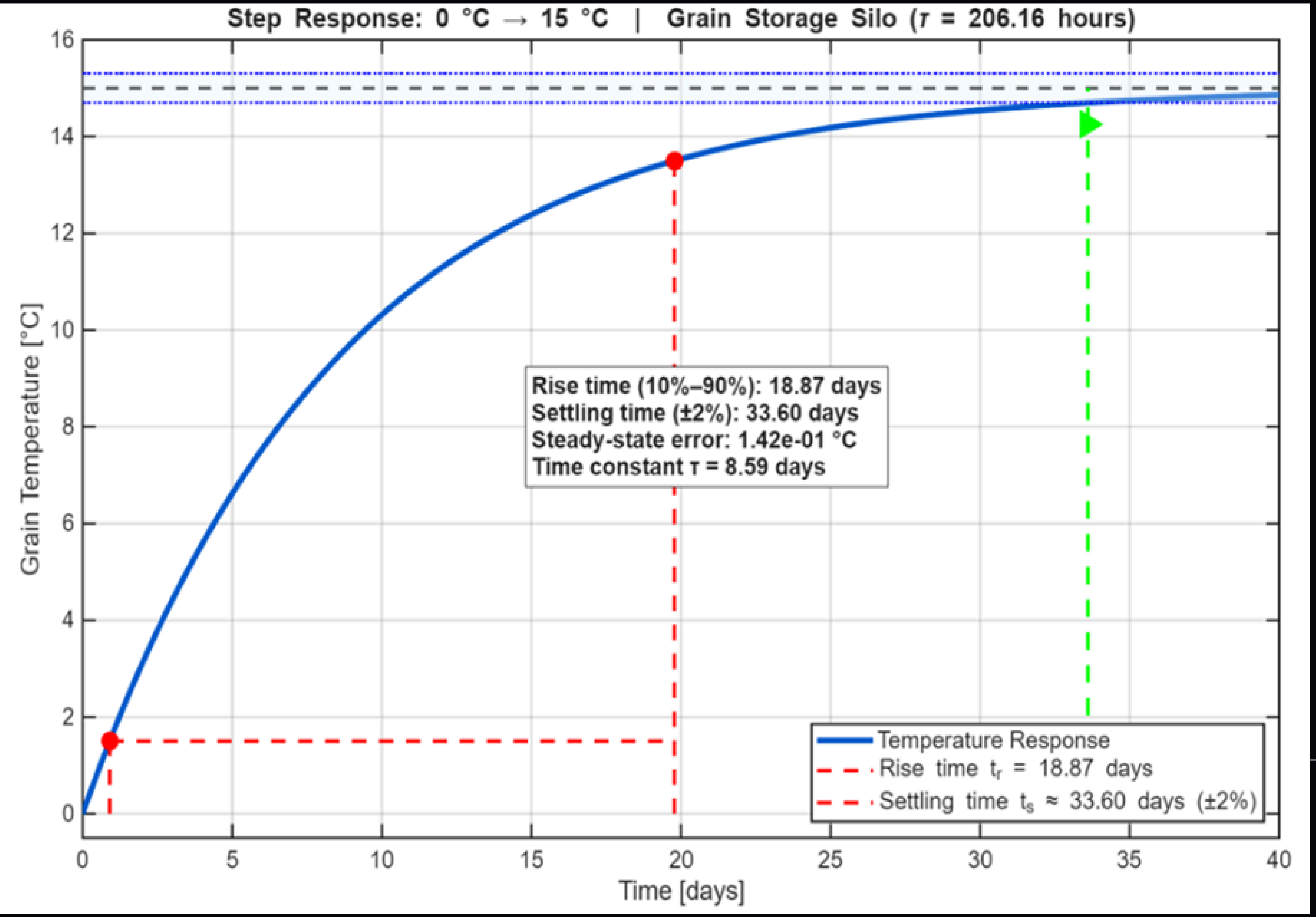
From appendix E the Bode plot reveals a classic first-order low-pass system with DC gain of 0 dB and a single corner frequency at ≈ 1.35 × 10^{-6} rad/s (τ = 206.16 hours ≈ 8.6 days). The magnitude rolls off at −20 dB/decade beyond , reaching exactly −3 dB at the corner frequency, while phase shifts from 0° to −90°, passing through −45° precisely at

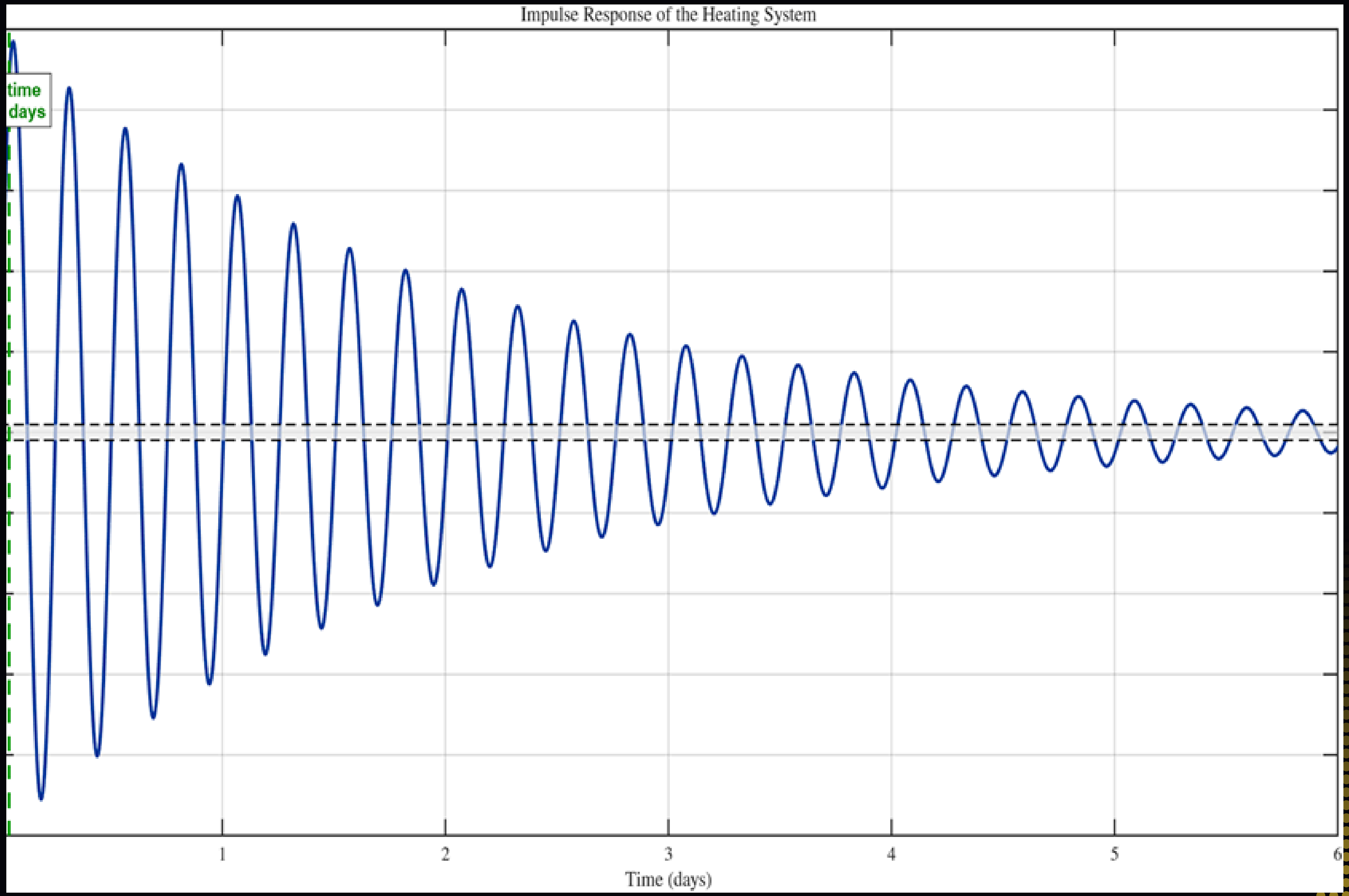
.

PROGRAM REALIZATION

MATLAB

STEP RESPONSE AND IMPULSE RESPONSE





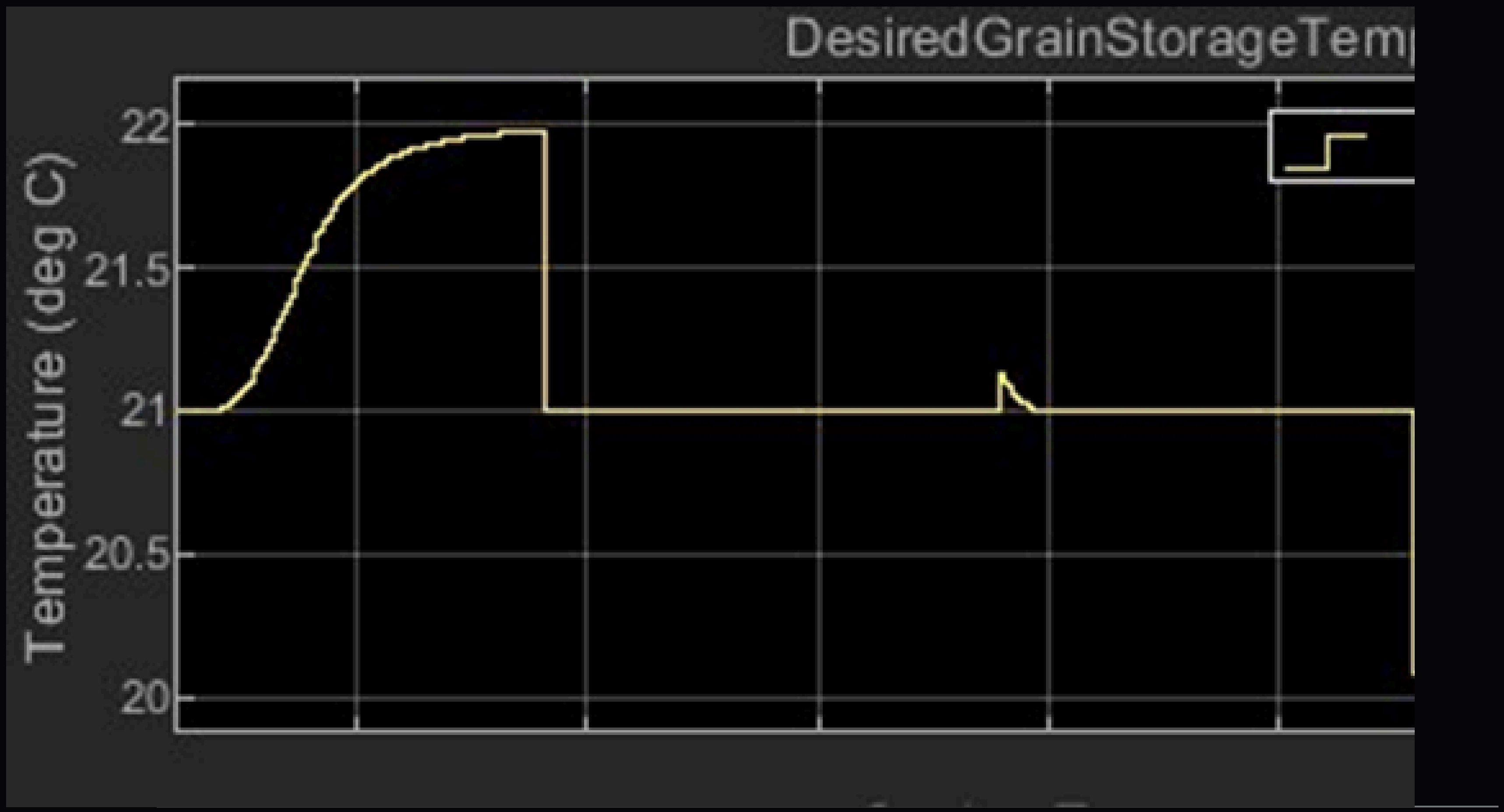
The provided figure illustrates the normalized step response of the grain storage heat exchanger system, characterizing its dynamic thermal behavior as a first-order linear process. The critical system parameter, the time constant , is visually identified at approximately 8.6 days, marked by the intersection where the response amplitude reaches 63.2% of its final steady-state value.

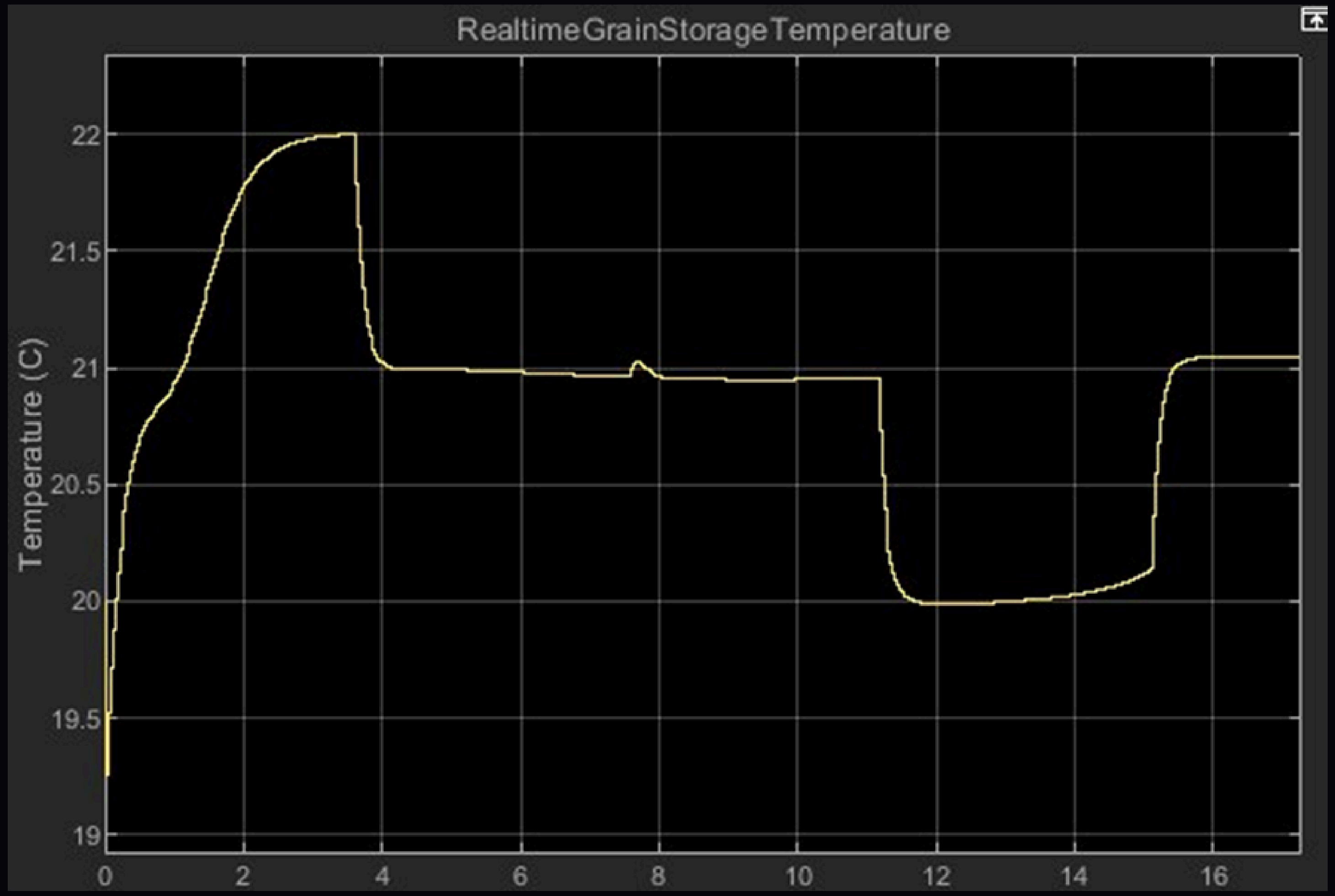
The plot shows the impulse response of a heat exchanger modeled as a second-order underdamped system from appendix C. An impulse input represents an instantaneous, infinitely brief heat pulse theoretical Dirac delta.

PROGRAM REALIZATION

MATLAB

SIMULATION RESULTS



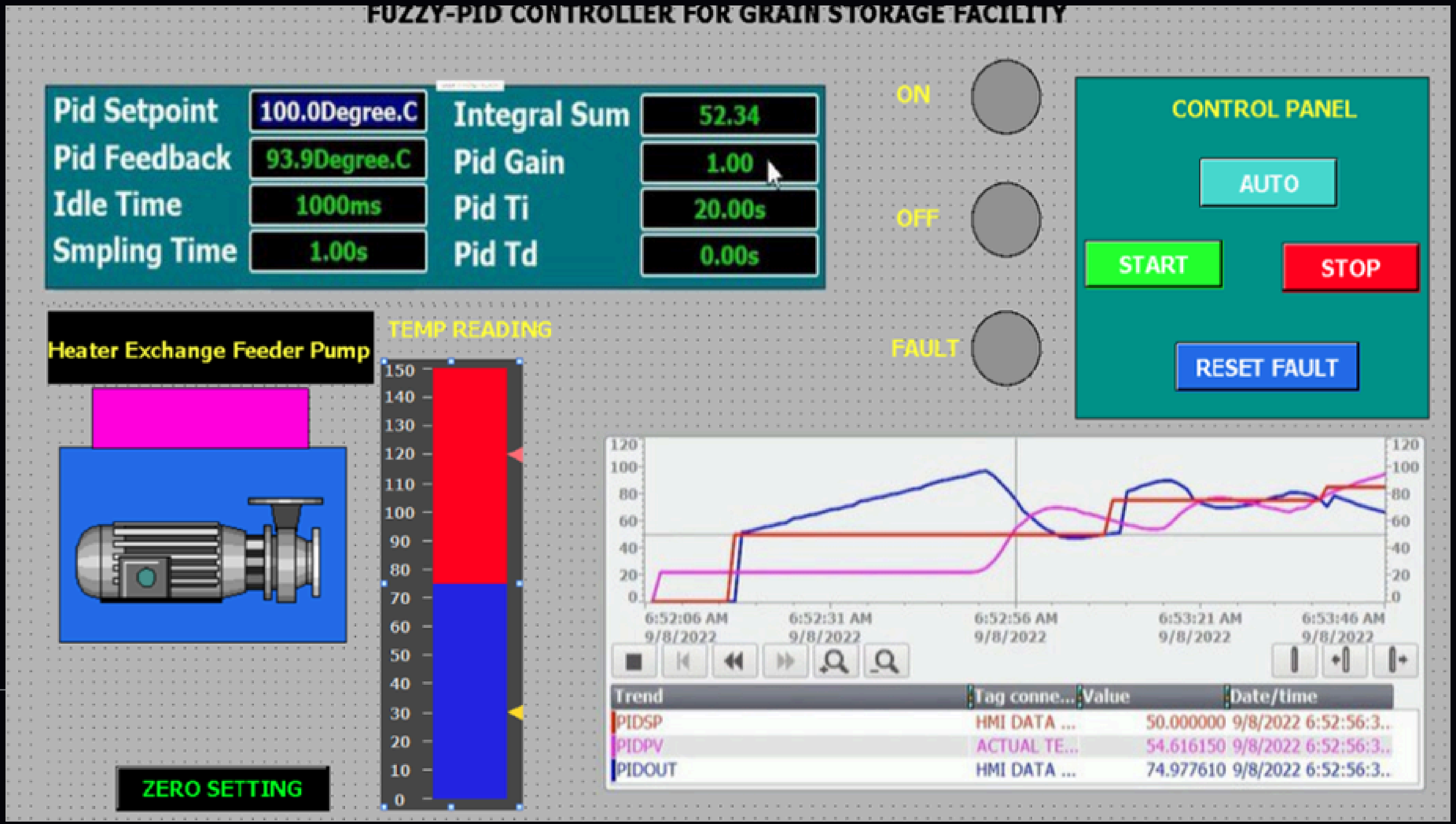


The closed-loop system performs as designed when the comfort mode is “variable”: the high-level fuzzy logic overrides any external setpoint commands and autonomously selects a cost-effective temperature of 20 °C under the given weather and pricing conditions. The low-level fuzzy PID controller then regulates the actual room temperature tightly around this autonomously determined setpoint with negligible steady-state error, minimal overshoot, and smooth heater modulation.

PROGRAM REALIZATION

SIEMENS

STEP RESPONSE AND IMPULSE RESPONSE

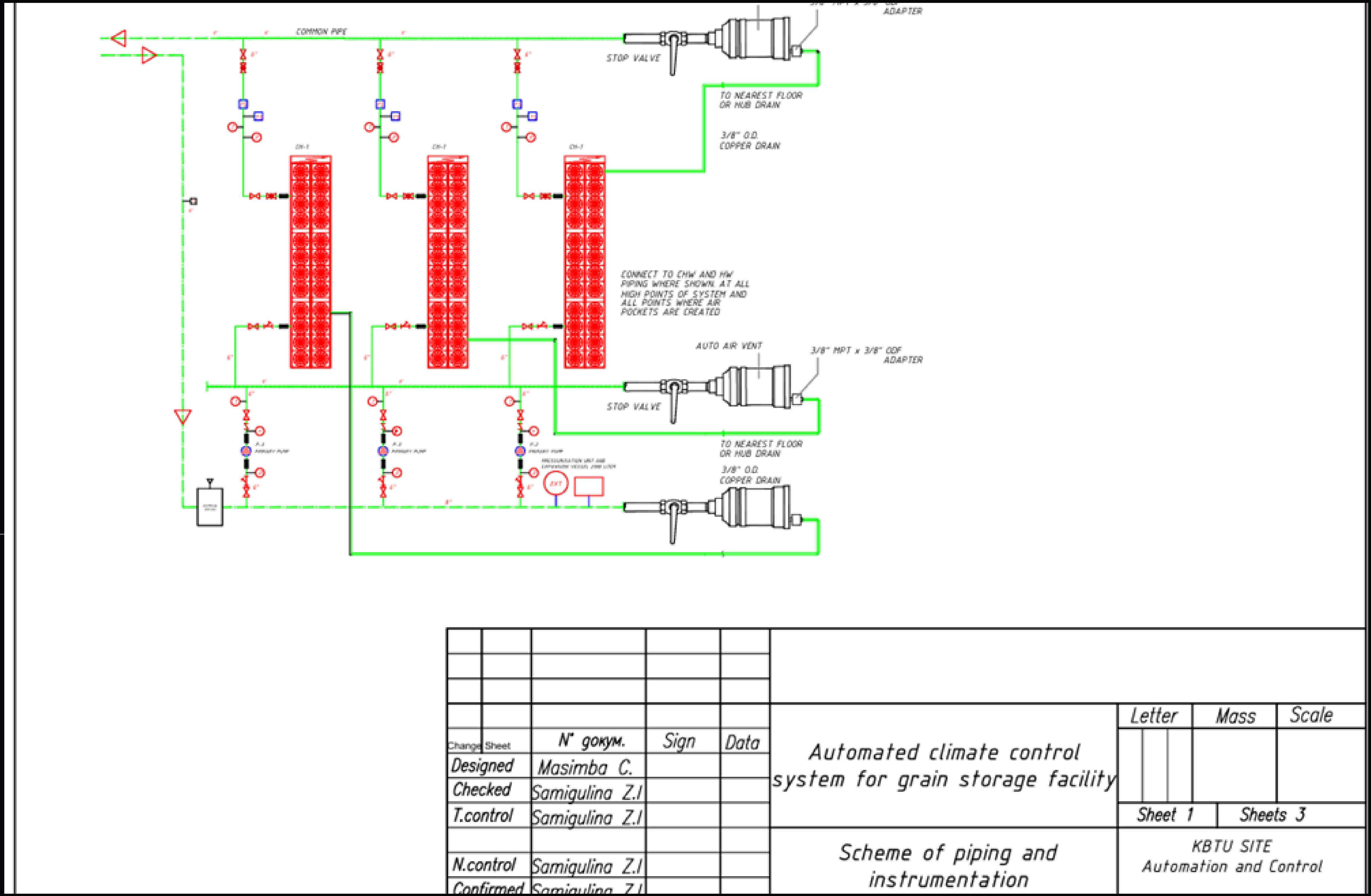


The illustrated control plant line diagram represents the complete closed-loop climate control system implemented for the automated grain storage silo using the Siemens ecosystem. At the central process is the storage silo itself. Its equipped with multiple SITRANS TS500 temperature cables distributed throughout the grain mass and SITRANS TH420 sensors monitoring headspace temperature and relative humidity. Warm, moist air is extracted from the silo headspace by a large aeration fan driven by a SINAMICS G120C variable-frequency drive, whose speed (0–100 %) is precisely regulated by the fuzzy-enhanced PID controller running in the SIMATIC S7-1200/1500 PLC.

REAL TIME REALIZATION

ENGINEERING DRAWING

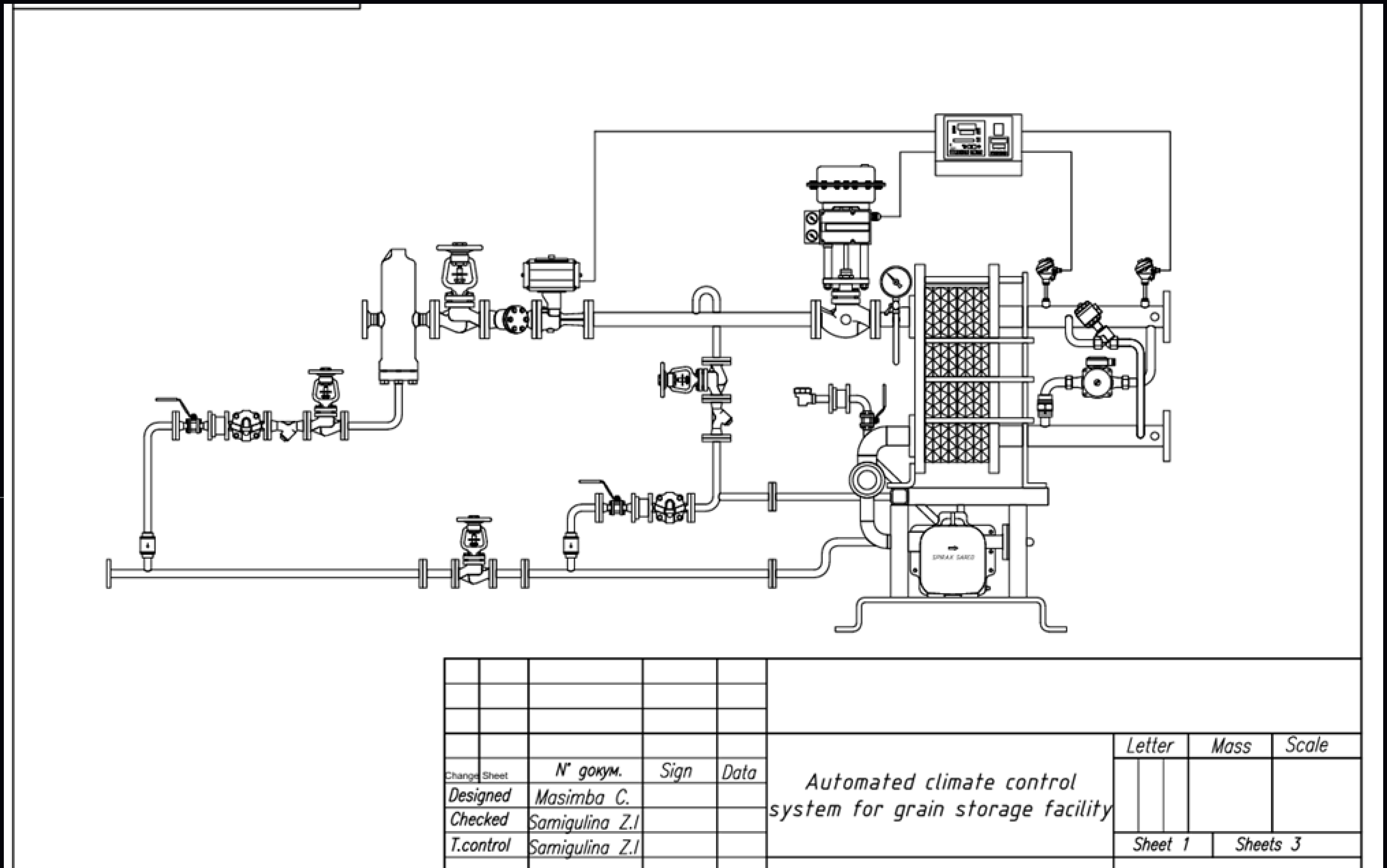
PI&ID DIAGRAM



REAL TIME REALIZATION

ENGINEERING DRAWING

HEAT EXCHANGER MODEL



CONCLUSION

The implementation of the automated grain storage climate control system, fully realized on the Siemens industrial automation platform within TIA Portal V19, successfully demonstrates a robust, intelligent, and energy-efficient solution for long-term post-harvest grain preservation. By integrating the SIMATIC S7-1200/1500 PLC, ET 200SP distributed I/O, SINAMICS G120 variable-frequency drives, SITRANS field instrumentation, and a hybrid fuzzy-enhanced PID controller over a unified PROFINET network, the system achieves precise regulation of critical micro-climate parameters temperature and relative humidity according to a scientifically grounded stepped cooling strategy.