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IMPROVING BTU MEASUREMENT ACCURACY FOR ENERGY-EFFICIENT BUILDINGS IN DISTRICT COOLING SYSTEMS USING ADVANCED MEASUREMENT AND CONTROL UNDER LOW-LOAD CONDITIONS IN SMART CITIES AND INFRASTRUCTURE.

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ABSTRACT— Accurate energy measurement and optimization are critical in District Cooling Systems (DCS) for achieving energy efficiency and operational reliability. This study proposes an innovative approach to enhancing BTU measurement accuracy by integrating advanced measurement and control systems into existing DCS infrastructure in smart cities. A secondary flowmeter is installed parallel to the primary system, and regression analysis is employed to model flow as a dependent variable, influenced by factors such as Pressure-Independent Balancing Control Valves (PIBCVs) and supply-return temperature differentials. Experimental results demonstrate significant improvements in flow measurement accuracy, which directly enhances BTU calculation precision. The findings contribute to optimizing DCS operations and achieving sustainable energy goals.

Keywords— District Cooling System, Energy Efficiency, BTU Measurement, Smart Cities.

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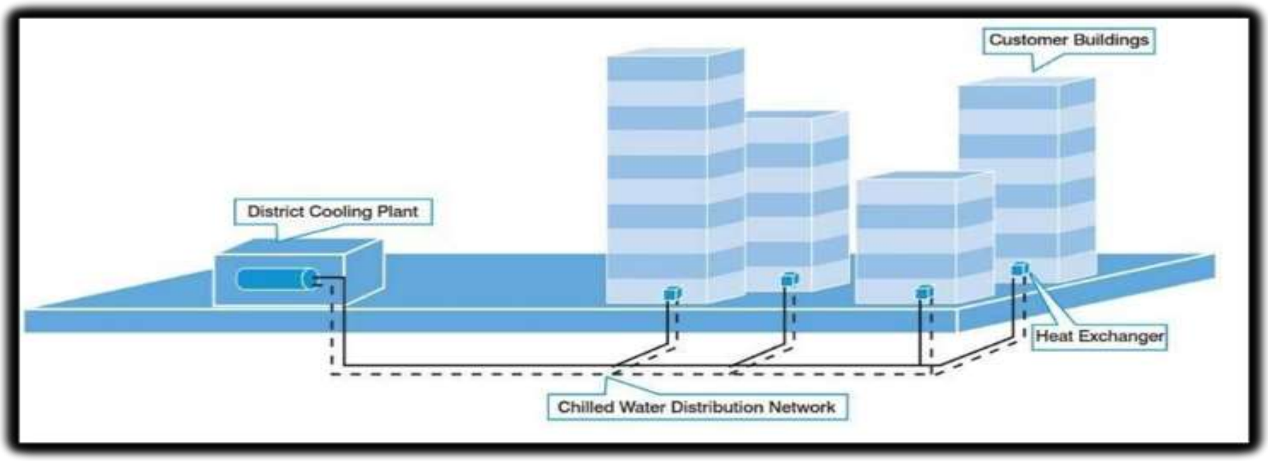
INTRODUCTION



"Figure 1: District Cooling System[1],[2]."

A. *District Cooling System*

This report provides a comprehensive technical analysis of District Cooling Systems (DCS), which distribute thermal energy through chilled water to multiple buildings. Utilizing an extensive network of underground pipes, DCS removes the need for individual cooling systems in each building.

A District Cooling System comprises several essential components that collectively ensure efficient chilled water distribution across multiple buildings. The primary elements include:

Chiller Plant: This serves as the central unit of the DCS, cooling water by utilizing a series of chillers to remove heat.

Chilled Water Distribution Network:
An insulated pipe system that delivers chilled water from the chiller plant to the buildings linked to it.
Heat Exchangers: In some setups, these are used to transfer cold energy without circulating chilled water directly inside the buildings.

Thermal Energy Storage (TES): Tanks made to hold excess chilled water during off-peak times, lowering peak energy demand and improving overall efficiency.

Pumping Stations: They ensure the smooth movement of chilled water throughout the distribution network to satisfy cooling needs.

SCADA Control Systems: These systems monitor and manage DCS operations, guaranteeing efficient energy utilization and stable temperature regulation.

Metering and Billing Infrastructure: This framework allows for precise measurement and billing of cooling energy usage.

Backup Systems: These include standby chillers and emergency generators to maintain cooling services without interruption.

When combined, these components improve the reliability, effectiveness, and sustainability of DCS when compared to conventional cooling methods.

DCS Load Operation at GIFT City

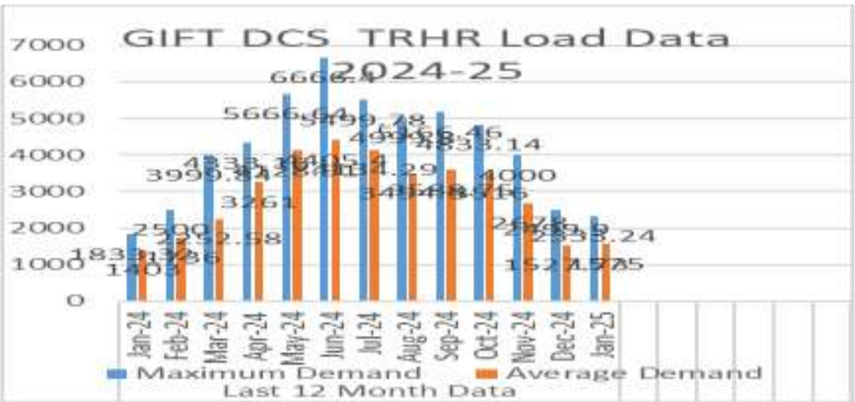


Figure 2: GIFT DCS TRHR Load Data 2024-25.

Figure 3: GIFT DCS Building wise Load sharing trend in Jan-2025.

At GIFT City, there is a 10,000 TR chiller plant operating alongside a 10,000 TRHR TES tank, serving 23 buildings.

The initial phase of operation encountered low building occupancy, leading to a minimal load on the District Cooling System (DCS), a scenario that was anticipated and accounted for during the design phase of the system. The following operational strategy has been implemented to effectively handle the 10,000-ton refrigeration (TR) capacity of DCP-1 during periods of low load.

A single 2,500 TR chiller is used to charge the Thermal Energy Storage (TES) tank at night during off-peak times. This process typically takes four to five hours. The chiller operates only at night to take advantage of cooler air temperatures and reduced electricity costs.

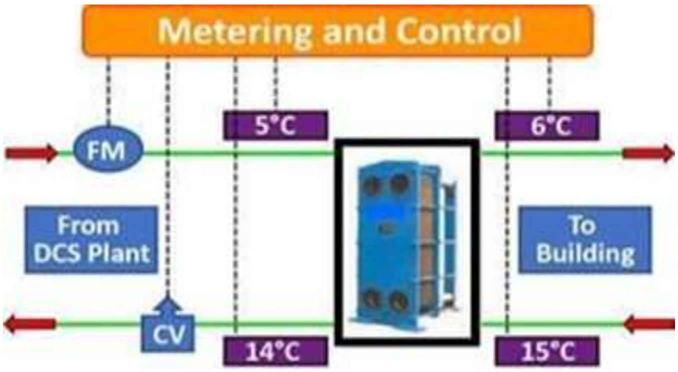
During the day, the TES tank is utilized to meet the cooling requirements of the buildings. To facilitate this, the TES tank pump and secondary pump are activated, eliminating the need for a chiller.

B. “Measurement and Control & Integration”

The main aim of the energy management system is to control auxiliary equipment and subsystems to optimize the electrical energy usage of the integrated cooling system. [2],[3].

An energy meter tracks the chilled water supply to each user or facility, with charges based on energy consumption. The metering approach implemented at the building level is illustrated in Figure 4. The metering and control systems of the District Cooling System (DCS) infrastructure include energy meters, pressure-independent control valves, and isolation valves [2],[3].

The control valve, which operates independently of pressure, ensures that the return temperature remains steady at 14°C for the District Cooling Plant (DCP) by adjusting flow rates based on changes in the return temperature. This is done to reduce the adverse impacts of chilled water.



“Figure 4: Measurement and Regulation[2],[3].”

During the design phase, considerable focus is placed on ensuring that the District Cooling System (DCS) operates seamlessly and delivers services consistently to users. Achieving this requires strong collaboration between the contractor selected by the developer and the building's design consultant. The DCS team at GIFT performs a detailed review of the Energy Transfer Station (ETS) room within each structure, paying close attention to equipment details such as access for operation and maintenance, as Figure 4 well as the inclusion of plate-type heat exchangers (PHEs) and pumps. Additionally, a comprehensive outline of how DCS interacts with the building systems is created to clarify the division of responsibilities[2] [3].

The structure of the control system for the District Cooling Plant relies on a fail-safe SCADA (Supervisory Control and Data Acquisition) alongside a PLC (Programmable Logic Controller). The PLC is essential for careful programming of both manual and automated logic controls. Automatic process sequences and logical functions are developed using ladder and functional block languages.

C. *“Instrumentation and Control (Automation)"*

All control sequences and safety measures are managed by the PLC. At the same time, the operator interacts with the system through the SCADA workstation. This workstation includes elements such as faceplates, color displays, alarm management, logging features, trend observation, diagnostics, and additional functionalities.

D. *“Energy Transfer Station Room in the Consumer System."*

The consumer system at the buildings consists of Plate Heat Exchangers (PHEs), chilled water pumps, chilled water pipes, Air Handling Units (AHUs), and air distribution setups. PHEs make it easier for the building's chilled water circuit to exchange thermal energy with the chilled water provided by the District Cooling System (DCS). Figure 4 illustrates the Energy Transfer Station (ETS) room located in GIFT-ONE Tower within GIFT City.

Currently, the District Cooling System provides air conditioning to 23 different buildings in GIFT City, which include GIFT ONE Tower, GIFT TWO Tower, Signature Tower, Data Centre, Aspire-1, and the C4 building, among others. In addition, various other buildings are under construction and will be integrated into the DCS framework in the near future.

“Figure 5: ETS room – GIFT ONE Tower[2],[3].”

E. *“Sustainable Development with DCS”*

The District Cooling System (DCS) promotes sustainable development by offering several key features: Efficient Operation: The DCS is optimized to minimize energy demand, enhancing energy efficiency in air conditioning and thus reducing CO2 emissions.

Reduced Water Consumption: The system limits the need for make-up water, sourcing cooling tower water from treated by-products of the Sewage Treatment Plant (STP), which helps preserve freshwater supplies.

Eco-Friendly Refrigerant: The DCS utilizes chillers powered by R134a, a non-CFC green refrigerant. By centralizing refrigerant storage at the DCS facility, the environmental impact of refrigerant usage is mitigated.

Resource Efficiency: The DCS supports sustainability efforts by diminishing the total reliance on natural resources through reduced facility capacity.

PROBLEM DEFENITION

In spite of the many benefits provided by the DCS, certain operational challenges remain. Recent billing analyses show seasonal energy losses, approximately ranging from 4% to 8% in the summer, with a rise to 15% or greater during winter and monsoon seasons. These losses highlight the need for an exhaustive evaluation of operational, measurement, and control methods to boost efficiency.

RESEARCH GAP

An examination of plant data indicates that flowmeters installed in each building show measurement inaccuracies when under low-load conditions, particularly during nighttime and winter. Such errors affect the accuracy of BTU calculations, which in turn impacts billing and energy efficiency. This research aims to bridge this gap by incorporating sophisticated flow measurement and control methods to improve system precision and overall performance.

METHOD

The estimation of chiller plant energy consumption is typically conducted using data-driven modelling techniques such as artificial neural networks (ANNs), regression modelling, and Bayesian networks[4]. A recent study explores sophisticated algorithms that establish a connection between demand and supply in district energy networks, thereby enhancing energy efficiency. These systems leverage user behavior analysis and meteorological data to ensure flexibility and stability in energy distribution, particularly in district cooling systems[5].

F. *System Overview*

The proposed framework integrates an additional flow meter in parallel with a control logic program within a programmable logic controller (PLC) to enhance redundancy and precision in the existing setup. The primary objective is to ensure accurate low-flow measurement, a critical factor influencing BTU calculations.

G. *Parameter Selection*

This study considers flow as the dependent variable, with the following independent parameters:
PIBCV Settings: Regulation of flow rates through pressure-independent control valves.

Supply and Return Temperatures: Key parameters influencing energy exchange efficiency.

H. *Regression Analysis*

A regression model is developed to quantify the relationship between flow and selected parameters. The analysis involves:

Application of linear and nonlinear regression techniques.

Validation through cross-validation and test datasets.

I. *Literature Review:*

Extensive literature reviews were conducted to explore enhancements in BTU measurement accuracy for energy-efficient buildings within district cooling systems. One study highlights energy conservation measure in district cooling, including the installation of heat recovery units and heuristic control of air supply cooling temperature, optimizing chilled water storage discharge and reducing electricity costs[6].

A case study on optimizing district cooling systems emphasizes assessing operational status and equipment interactions. Recommendations include advanced measurement and control strategies such as check valve replacement and pump frequency adjustments, leading to substantial energy efficiency improvements in buildings[7][8].

Another study proposes a model-free control strategy using deep reinforcement learning to enhance operational flexibility in district cooling systems, addressing complex thermal dynamics and uncertain cooling demands, ultimately improving energy efficiency and ensuring operational security[9].

Advanced measurement and control systems in district cooling networks optimize operations by improving load prediction and enabling coordinated management between central plants and users. These improvements help mitigate dynamic performance issues and reduce energy consumption during peak hours[10].

Predictive models developed through regression analysis can be used to forecast the impact of control parameter modifications on system behavior. This proactive approach enables real-time adjustments to ensure optimal system performance and prevent inefficiencies. Model Predictive Control (MPC) is employed to define a control strategy that minimizes an objective function dependent on plant dynamics[11].

Hybrid control strategies have demonstrated effectiveness in stabilizing energy systems and enhancing thermal energy distribution efficiency[12].

Energy simulation tools such as TRNSYS, EnergyPlus, and OpenModelica have been utilized for district cooling system modelling and analysis, allowing for the identification of high-energy consumption areas and inefficiencies under different operating conditions[13],[14].

A case study examined a water-cooled chiller plant with multiple chillers and cooling towers for condenser water setpoint optimization. The study demonstrated a 5% reduction in energy consumption through condenser water setpoint optimization, with minimal benefits observed when reducing the optimization time horizon[15],[16].

To evaluate the impact of advanced control systems, multiple case studies were analysed. A pilot project model was applied to the District Cooling System (DCS) plant and distribution networks at Gift City, specifically targeting the GIFT 1 building. Given that GIFT 1 exhibits the highest load consumption among all buildings, this implementation maximized BTU measurement accuracy.

BTU Measurement Accuracy:

Accurate flow measurement directly impacts BTU calculations, as BTU is computed using:

$$\mathrm{BTU} = \mathrm{m} \cdot \mathrm{Cp} \cdot (\mathrm{Tsupply} - \mathrm{Treturn})$$

Where:

$\dot{m}$ is the mass flow rate.

Cp is the specific heat capacity of the fluid.

(Tsupply−Treturn) is the temperature difference

A regression model for flow measurement minimizes inaccuracies caused by sensor errors, installation constraints, and system dynamics. A parallel flow meter was introduced to enhance measurement precision.

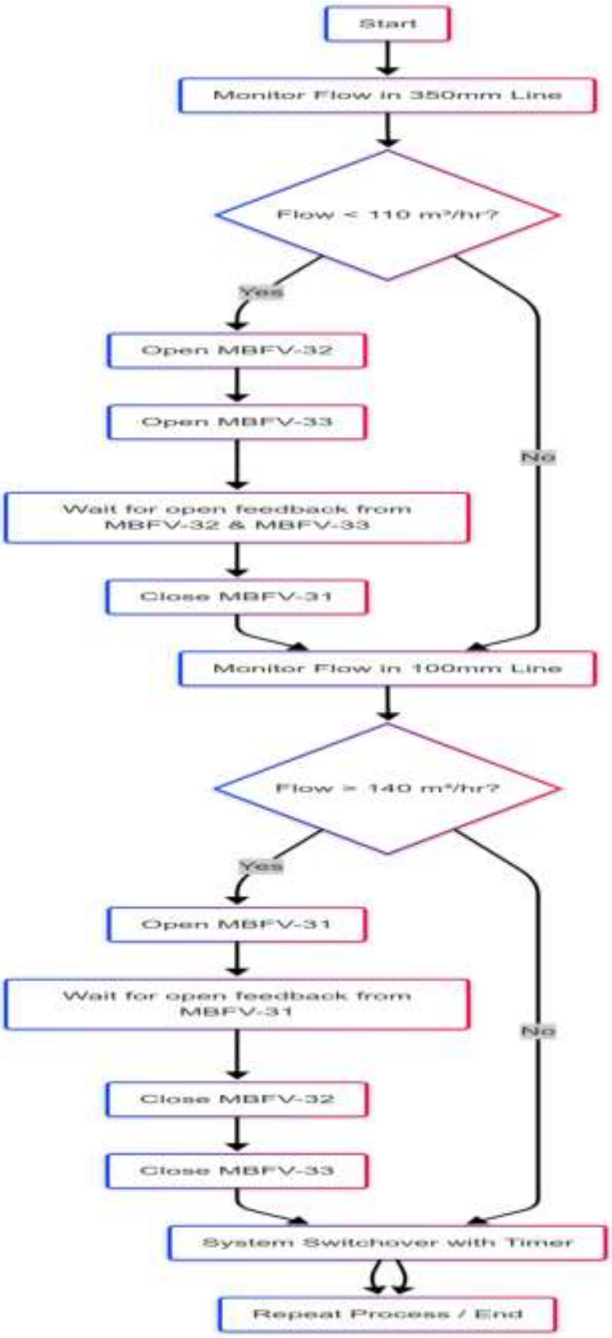
Key Metrics Comparison

Season	Metric	DN 350 Model	DN 100 Model
Summer (2024–2025)	Multiple R	0.171957	0.912339
	R²	0.029569	0.832362
	Adjusted R²	-0.012623	0.785715
	Standard Error	0.387696	0.22357
	Observations	49	50
Monsoon (2024–2025)	Multiple R	0.964564	0.997746
	R²	0.930383	0.995498
	Adjusted R²	0.895805	0.994710
	Standard Error	0.709167	1.837368
	Observations	48	48
Winter (2024–2025)	Multiple R	0.9997	0.999995

	R^2	0.999401	0.999991
	Adjusted R^2	0.978567	0.979157
	Standard Error	0.423979	0.055381
	Significance F	1.33695527E-77	3.71E-12
	Observations	49	49

J. *Philosophy for GIFT-1 Bypass line Flow meter Operation*

Below is the flow chart shown for SCADA algorithm.



When the flow in the 350mm diameter drops to below 110 m3/Hr, both MBFV-32 and MBFV-33 will open first then MBFV-31 will close after getting open feedback of MBFV-33 and MBFV-32.

When the flow in the 100mm diameter exceeds the flow 140 m3/Hr, MBFV-31 will open first then both MBFV-33 and MBFV-32 will close after getting open feedback of MBFV-31. A timer has been placed in a program to facilitate system switchover based on varying flow conditions.
Reports:
Reports for motorized valve status and DN100 BTU meters to be configured in SCADA.
BTU Totalizer Report to be configured as per following details:
BTU Totalizer = DN350mm BTU Totalizer + DN100mm BTU Totalizer.

Legends:

MBFV-31: Motorized operated butterfly valve of 350mm

MBFV-32: Motorized operated butterfly valve of 100mm

MBFV-33: Motorized operated butterfly valve of 100mm

To identify optimal operational parameters and control strategies for minimizing system losses in the district cooling system, we implemented SCADA-based optimization techniques through a pilot project. This project focuses on enhancing low-flow measurement accuracy in buildings, particularly during nighttime hours and the summer, winter and monsoon seasons.

The P&I Diagram below illustrates the pipeline configuration and BTU measurement equipment, highlighting the system's state before and after the installation of control mechanisms at the GIFT1 building.

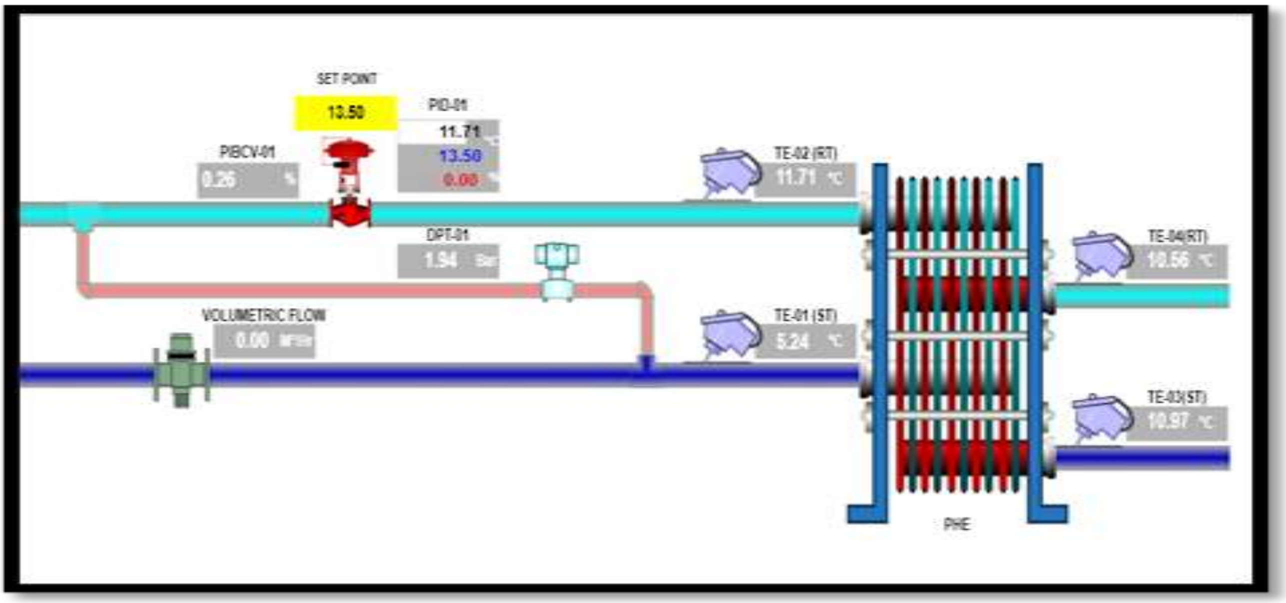


Figure 6: Before Pilot Project for GIFT 1.

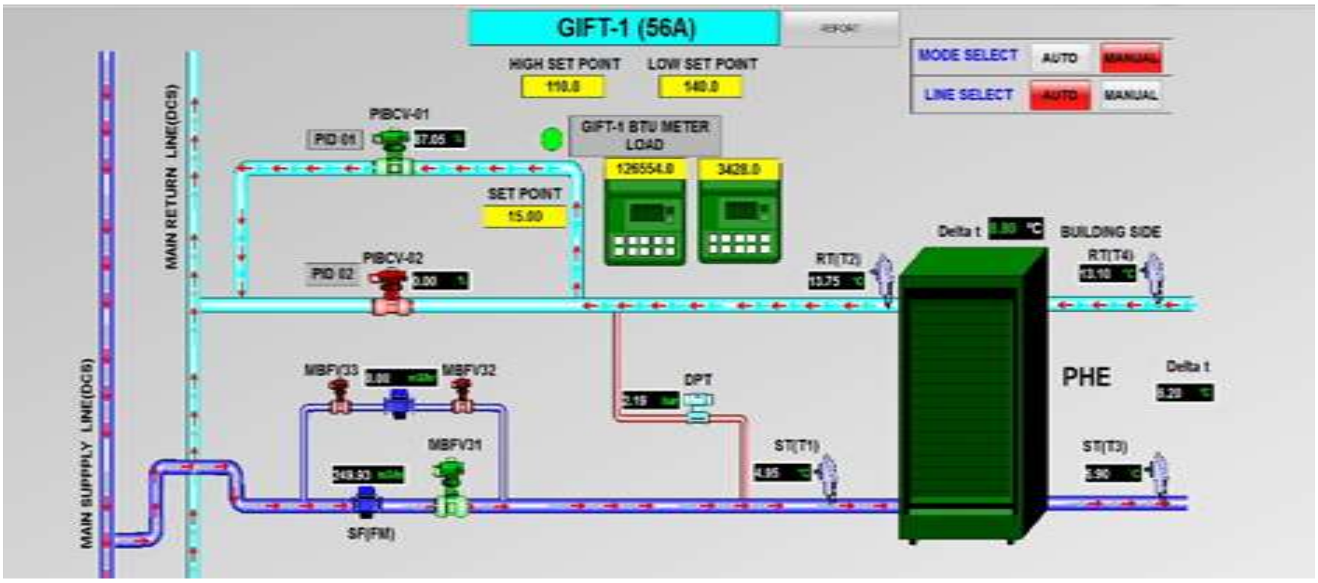


Figure 7: After Pilot Project for GIFT 1.

K. *Metering Components and Their Accuracy*

Resistance Temperature Detectors (RTDs)

Two RTDs are installed to monitor the chilled water temperature at the supply and return lines of the DCS.

Accuracy: ±0.25°C at 0°C

Purpose: Measure temperature differential to calculate thermal energy.

Electromagnetic Flow Meters

Electromagnetic flow meters are used to measure the chilled water flow rate.

Accuracy:

Above 0.5 m/s velocity: ±0.5% of the measured value

Below 0.5 m/s velocity: Significant variations observed, especially during low-load periods.

Measurement Range: Sized to handle 20% higher flow than the building’s ultimate load capacity.

Calibration Procedures

Flow Meter Calibration

Annual calibration is performed by an NABL-approved agency using a portable ultrasonic flow meter.

Portable Ultrasonic Flow Meter Accuracy: ±2% of the measured value

Electromagnetic Flow Meter Accuracy: ±0.5% of the measured value as per NABL accreditation Chart[17]

RTD Calibration

RTDs are calibrated annually using a standard temperature bath and a master RTD sensor.

Allowable Accuracy: ±0.25°C at 0°C

Figure 8: Reference Datasheet for Flow meter selection for related velocity[17].

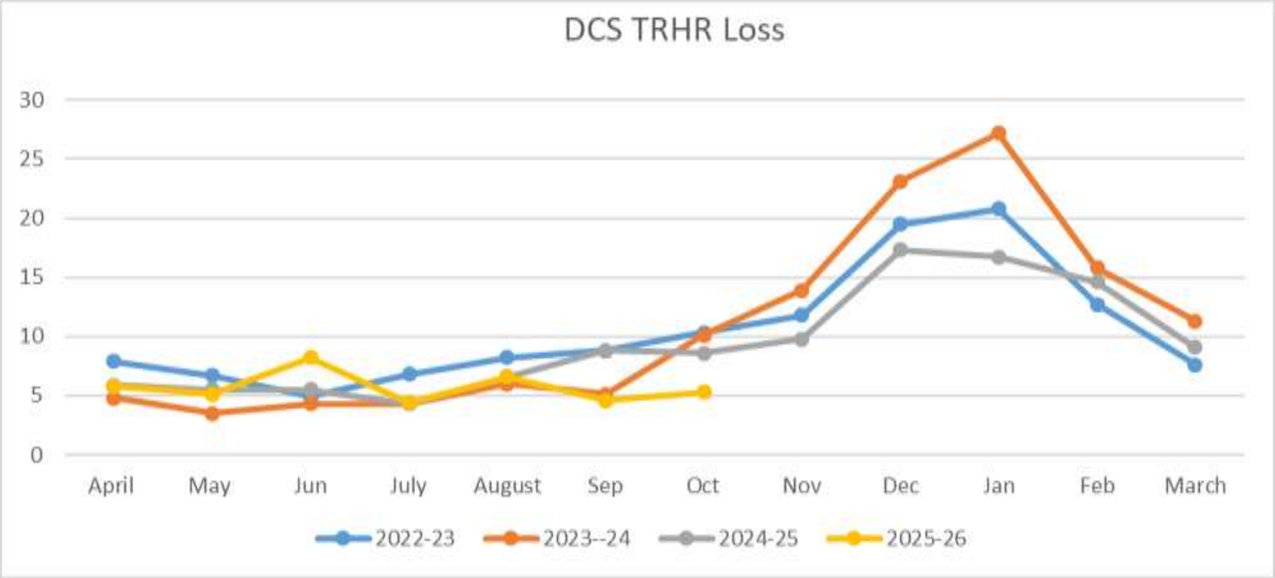


Figure 9: Plant Performance Data Chart after Success of Pilot Project.

RESULTS & DISCUSSION

The study demonstrates significant energy savings through improved BTU meter accuracy, particularly in low-flow conditions where system design flow is below the minimum required threshold. The pilot project implementation at GIFT 1 resulted in an average increase of around **34.7%** in TR-Hr consumption, validating the effectiveness of the methodology.

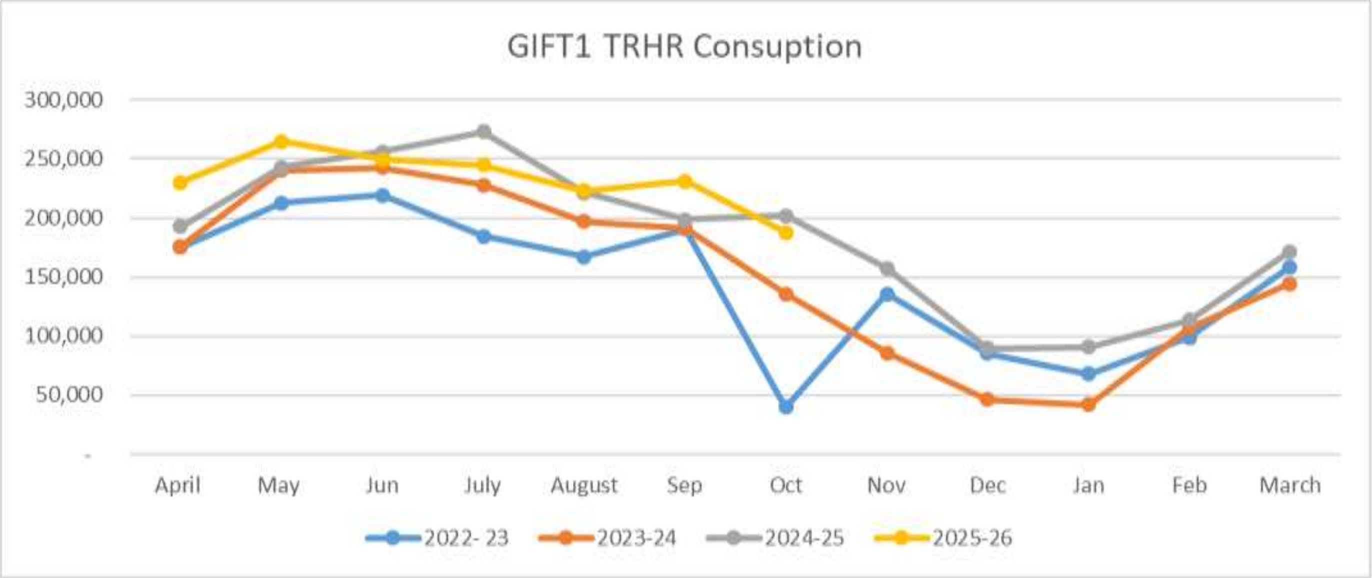


Figure 10: GIFT1 Data Chart after Success of Pilot Project.

Projected Impact and Scalability

- Energy Savings: Initial annual improvement in BTU GIFT1 Measurement Accuracy across Year increase of 91,250 TR-Hr was expected as per Figure 11.
- After Pilot Project Implemented at GIFT1 in November 2024, average BTU GIFT1(April–Mar 2023–24): 1,53,147 Tr Hr. and the average BTU GIFT1(April–Mar 2024–25): 184,159 Tr Hr.
- Improvement in BTU GIFT1 Measurement Accuracy across Year: +34.7%.
- Financial Saving Impact: ₹33.9 Lakhs/year saving.
- Improved measurement accuracy and control optimization enhanced energy accountability under low ΔT conditions.
- Economic Feasibility: Estimated payback period of five months.
- Expansion Potential: The methodology is applicable to 23 buildings within GIFT City for further energy efficiency improvements.
- Current Implementation: The pilot project is currently being extended to GIFT 2.

CONCLUSION

This research presents a novel approach to optimizing BTU measurement accuracy in District Cooling Systems under low-load conditions. By integrating secondary flowmeters, regression analysis, and advanced SCADA-based control mechanisms, significant improvements in flow measurement precision were achieved. The study's findings contribute to reducing energy losses, improving billing accuracy, and enhancing the overall efficiency of DCS operations.

FUTURE SCOPE

Future research avenues include examining the scalability of integrating control systems into various district cooling configurations, looking into possible synergies between measurements and control systems and renewable energy sources and improving simulation models to more accurately forecast energy savings. Furthermore, based on initial load, the study recommends examining the long-term effects of control system integration on plant efficiency and environmental footprint.

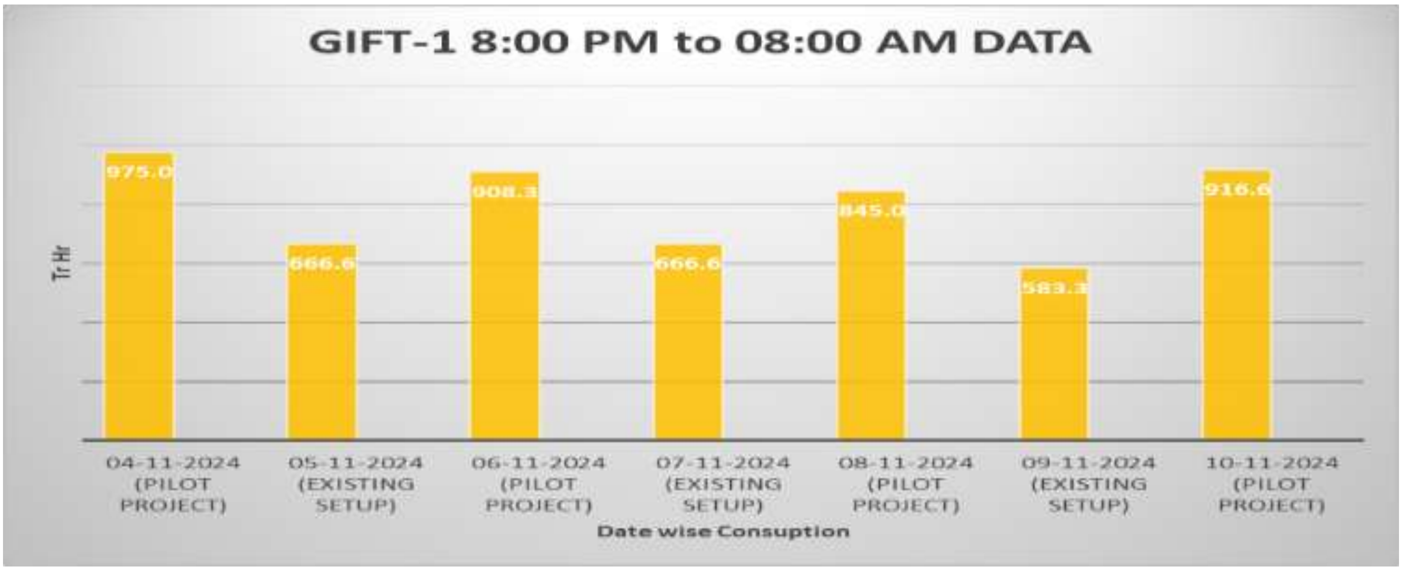


Figure 11: GIFT 1 Building Pilot Project Data Comparison Chart.

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