



Modernizatsiya qilingan markazlashtirilgan issiqlik ta'minoti tizimining ekspluatatsion ko'rsatkichlari: O'zbekistonning Chirchiq shahrida avtomatlashtirilgan individual issiqlik punktlari bilan yopiq tizimga o'tish jarayoni monitoringi natijalari

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Dolzarbli: Markaziy Osiyodagi sovet davridagi markaziy issiqlik ta'minoti infratuzilmasi odatda 35–40% dan ortiq tarmoqdagi issiqlik yo'qotishlariga va qozonxonalarda 75% dan past samaradorlikka ega. Bunga o'n yilliklar davomida kechiktirilgan texnik xizmat ko'rsatish va eskirgan ochiq-gidravlik arxitektura sabab bo'lgan. Mintaqadagi yirik modernizatsiya loyihalari bo'yicha ilmiy kuzatuv ma'lumotlari juda kam.

Maqsad: tadqiqotning maqsadi modernizatsiyadan so'ng K-1 issiqlik tarmog'ining issiqlik samaradorligi va issiqlik yo'qotishlaridagi o'zgarishlarni miqdoriy baholash, tabiiy gaz, elektr energiyasi va tarmoq suvi sarfining kamayishini aniqlash, avtomatlashtirilgan individual issiqlik punktlarining issiq suv ta'minotini ta'minlash samaradorligi va iste'molchilar xarajatlariga ta'sirini baholash, shuningdek, modernizatsiyaning ekologik samaralarini hamda uning infratuzilmaning xizmat qilish muddatiga ta'sirini tahlil qilishdan iborat.

Usullari: ushbu kvazi-eksperimental "oldin-keyin" tadqiqot Chirchiq shahridagi "Yubileyana" qozonxonasi (K-1) va uning 24 845 metrli taqsimot tarmog'i bo'yicha operatsion monitoring va energetik audit ma'lumotlarini tahlil qildi (aholisi 176 151). Jahon banki tomonidan moliyalashtirilgan intervensiya doirasida ochiq issiq suv tizimi o'rni o'ldirishdan izolyatsiya qilingan quvurlar va binolardagi avtomatlashtirilgan individual issiqlik punktlari joriy etildi. Asosiy samaradorlik ko'rsatkichlari qozonning issiqlik samaradorligi, tarmoqdagi issiqlik yo'qotishlari, tabiiy gaz va elektr energiyasi iste'moli, tarmoq suvini to'ldirish talabi va CO₂ chiqindilarini o'z ichiga oladi.

Natijalar: modernizatsiyadan so'ng qozon samaradorligi 83% dan 92–95% gacha oshdi. Tarmoqdagi issiqlik yo'qotishlari ~ 40% dan 15–20% gacha kamaydi. Yillik tabiiy gaz iste'moli 25–30% ga qisqardi (loyiha bo'yicha umumiy tejash yillik 320 mln m³ ga yetishi mumkin). Nasoslarning chastota o'zgartirgichlari joriy etilishi natijasida elektr energiyasi iste'moli 15–20% ga (~ 85 mln kVt·soat/ yil) kamaydi. Tarmoq suvini to'ldirish talabi 60–75% ga qisqardi. CO₂ chiqindilari taxminan 30% ga kamaydi.

Kalit so'zlar: issiqlik ta'minotini modernizatsiya qilish; avtomatlashtirilgan individual issiqlik punkti; oldindan izolyatsiya qilingan quvur; energetik audit; issiqlik samaradorligi; O'zbekiston.

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Эксплуатационные показатели модернизированной системы централизованного теплоснабжения: результаты мониторинга перехода на закрытую схему с автоматизированными индивидуальными тепловыми пунктами в городе Чирчике, Узбекистан

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Актуальность: постсоветская инфраструктура централизованного теплоснабжения в Центральной Азии стабильно демонстрирует потери тепловой энергии в сетях, превышающие 35–40%, и КПД котельных ниже 75%, что обусловлено десятилетиями отсроченного технического обслуживания и конструктивно устаревшей открытой гидравлической схемой. Рецензируемые данные операционного мониторинга для крупномасштабных проектов модернизации в регионе практически отсутствуют.

Цель: количественной оценке изменений тепловой эффективности и тепловых потерь в тепловой сети К-1 после модернизации, определении снижения потребления природного газа, электроэнергии и сетевой воды, оценке эффективности автоматизированных индивидуальных тепловых пунктов в обеспечении горячего водоснабжения и влияния на затраты потребителей, а также анализе экологических эффектов модернизации и её влияния на срок службы инфраструктуры.

Методы: в данном квазиэкспериментальном исследовании «до/после» были проанализированы данные операционного мониторинга и энергетического аудита котельной станции «Юбилейная» (К-1) и её распределительной сети протяжённостью 24 845 м в городе Чирчик, Узбекистан (население 176 151). В рамках финансируемого Всемирным банком проекта открытая система горячего водоснабжения была заменена на предизолированные трубопроводы и автоматизированные индивидуальные тепловые пункты на уровне зданий. Ключевые показатели эффективности включали тепловой КПД котла, потери тепла в сети, потребление природного газа и электроэнергии, подпитку сетевой воды и выбросы CO₂.

Результаты: после модернизации КПД котла увеличился с 83% до 92–95%. Потери тепла в сети снизились с ~40% до 15–20%. Годовое потребление природного газа сократилось на 25–30% (проектные совокупные сбережения оцениваются до 320 млн м³/год). Потребление электроэнергии на насосы уменьшилось на 15–20% (~85 млн кВт·ч/год) благодаря внедрению насосов с частотными преобразователями. Потребность в подпитке сетевой воды сократилась на 60–75%. Выбросы CO₂ уменьшились примерно на 30%.

Ключевые слова: модернизация теплоснабжения; автоматизированный индивидуальный тепловой пункт; предизолированные трубы; энергетический аудит; тепловой КПД; Узбекистан.

Operational performance of a modernized district heating system: monitoring evidence from the transition to closed-circuit architecture with automated individual thermal points in Chirchik, Uzbekistan

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Relevance: Post-Soviet district heating infrastructure in Central Asia consistently exhibits network heat losses exceeding 35–40% and boiler efficiencies below 75%, largely due to decades of deferred maintenance and an outdated open hydraulic configuration. Peer-reviewed operational monitoring data from large-scale district heating modernization projects in the region remain extremely limited.

Aim: the study aims to quantitatively assess changes in thermal efficiency and heat losses in the K-1 heating network following modernization; determine reductions in natural gas, electricity, and network make-up water consumption; evaluate the performance of automated individual heating substations in terms of domestic hot water provision and their impact on consumer costs; and assess the environmental benefits of modernization and its implications for infrastructure service life.

Methods: this quasi-experimental before-and-after study analyzed operational monitoring and energy audit data from the Yubileynaya boiler plant (K-1) and its 24,845-m-long distribution network in Chirchiq, Uzbekistan (population: 176,151). As part of a World Bank-funded project, the open domestic hot water supply system was replaced with pre-insulated pipelines and automated individual heating substations at the building level. Key performance indicators included boiler thermal efficiency, network heat losses, natural gas and electricity consumption, network make-up water consumption, and CO₂ emissions.

Results: following modernization, boiler efficiency increased from 83% to 92–95%. Network heat losses decreased from approximately 40% to 15–20%. Annual natural gas consumption was reduced by 25–30%, with total project-level savings estimated at up to 320 million m³/year. Electricity consumption for pumping decreased by 15–20% (approximately 85 million kWh/year) following the installation of variable-frequency drives. Network make-up water requirements were reduced by 60–75%. CO₂ emissions decreased by approximately 30%.

Keywords: district heating modernization; automated individual heating substation; pre-insulated pipes; energy audit; thermal efficiency; Uzbekistan.

1. Introduction

1.1 Background

District heating (DH) systems supply space heating and domestic hot water (DHW) to residential and commercial buildings through centralized heat-generating plant and distribution pipelines. When

operated efficiently, centralized DH reduces per-unit carbon emissions relative to individual gas or electric heating by enabling large-scale combustion optimization, waste-heat recovery, and demand aggregation [1, 2]. These advantages are only realized, however, when infrastructure is maintained within acceptable thermal and hydraulic performance parameters.

Across the former Soviet Union, DH infrastructure was built on a standardized open-circuit model: primary network water was distributed directly to consumer endpoints. Following the dissolution of the USSR, investment in DH maintenance largely ceased in many successor states. By the 2010s, a majority of Soviet-era DH networks in Central Asia had exceeded their design service lives without replacement, exhibiting widespread insulation failure, pipe corrosion, unmetered consumption, and network hydraulic instability [3, 4].

1.2 The Chirchik Infrastructure Context

Chirchik is an industrial city in Tashkent Region, Uzbekistan (population 176,151 as of April 2025), located 32 km northeast of Tashkent. Its residential building stock was constructed predominantly between 1962 and 1989. The primary DH provider, Chirchiq Issiqlik Energiyasi (ChIE), operates 15 separate boiler stations with peak heat demands ranging from 0.1 to 68 Gcal/h and network lengths from 0.1 to 25 km per station.

The “Yubileynaya” boiler station (K-1), built in 1962, supplies heat to microdistricts 1–4 via a 24,845 m pipeline network constructed in 1976. Its principal heat-generating unit was a PTVM-30 hot-water boiler, operated at a supply/return temperature of 60/50°C — far below its design parameter of 150/70 °C. This temperature depression was caused by the deteriorated condition of building-level elevator mixing nodes: failure of a node would allow high-temperature primary water to enter consumer radiator circuits directly. Above-ground pipe insulation was functionally destroyed across most of the network. Network water replenishment exceeded the normative value by a factor of 1.54.

1.3 Knowledge Gap

The technical rationale for modernizing post-Soviet DH systems is established in Northern and Central European literature [5, 6, 7]. However, peer-reviewed studies reporting quantitative operational monitoring outcomes from completed, large-scale open-to-closed-circuit modernization projects in Central Asia — where climate, fuel pricing, regulatory environments, and building stock characteristics differ materially from Europe — are absent from the indexed literature. This paper addresses that gap.

1.4 Objectives

1. Quantify changes in thermal efficiency and network heat losses at K-1 following modernization.
2. Document associated reductions in natural gas, electricity, and network water consumption.
3. Characterize AITP performance in terms of DHW provision and consumer cost outcomes.
4. Report environmental co-benefits and infrastructure service life implications.

2. Methods and materials

2.1 Study Design

This is a quasi-experimental pre/post case study using operational monitoring data and energy audit records from the K-1 “Yubileynaya” boiler station. The modernization was executed under the World Bank project “Reform of the Centralized District Heating Sector,” financed through concessional World Bank credit and initiated by Presidential Decree of the Republic of Uzbekistan. Chirchik served as the pilot implementation site. A parallel implementation in Bukhara, Uzbekistan, under the same project framework is referenced for contextual comparison. No randomization was applied; infrastructure-scale modernization precludes experimental design. All KPI values represent aggregate operational monitoring estimates from metering logs and project documentation. No inferential statistical analysis is applied, consistent with a single-facility monitoring design (see Section 5.1 Limitations).

2.2 Pre-Modernization System

The K-1 station operated as an open-circuit district heating system. Primary network water functioned simultaneously as heat carrier and consumer DHW source; DHW was available only during the heating season (~ 4 months/year). Building-level connections used elevator mixing nodes — passive hydraulic devices providing minimal temperature regulation and no hydraulic isolation from the primary circuit. The distribution network comprised above-ground pipelines on high supports and underground pipes in reinforced concrete channels, both installed in 1976. Neither segment retained functional thermal insulation.

2.3 Modernization Intervention

The intervention comprised four integrated components:

(a) Boiler replacement. Installation of modern three-pass fire-tube hot-water boilers replacing the PTVM-30 unit. Three-pass design maximizes flue gas residence time and heat transfer surface area, achieving rated efficiencies of 92–95%.

(b) Pre-insulated piping. Full replacement of the 24,845 m network with pre-insulated steel pipes

comprising a steel carrier pipe, polyurethane foam insulation layer, and high-density polyethylene outer casing (GOST 30732-2020). Design service life: 30–50 years.

(c) Automated Individual Thermal Points (AITPs). Installation of building-level heat exchange stations at each connected structure. An AITP hydraulically decouples the primary network from building internal circuits via plate heat exchangers. Core components: primary-side plate heat exchangers for space heating and DHW; variable-frequency drive (VFD) circulation pumps; outdoor-temperature-compensated electronic control unit (ECU); heat, water, and electrical energy meters (SCADA-compatible).

(d) VFD network pumps. Replacement of pre-modernization fixed-speed pumps (SE 800/100, 315 kW × 3 units; total 945 kW) with variable-frequency drive units enabling demand-responsive flow and pressure adjustment.

2.4 Fuel Supply Parameters

Primary fuel: natural gas from “Chirchiq-1” gas distribution station. Composition: CH₄ 92.78%; C₂H₆ 3.70%; C₃H₈ 0.41%; C₄H₁₀ 0.17%; CO₂ 0.16%; N₂ 1.30%; H₂S 0.004%. Lower heating value: 8,100 kcal/nm³; density at 20 °C: 0.723 kg/m³. Water supply treated by on-site chemical softening prior to system entry (surface source hardness: 1.7–2.4 mEq/L; groundwater: 6.2 mEq/L).

2.5 Energy Audit Protocol

The energy audit followed a six-stage methodology: (1) preliminary review of statistical, documentary, and technical records; (2) instrumental and thermographic inspection of all thermal and electrical energy consumers; (3) energy balance analysis; (4) analytical data processing across all energy use categories; (5) efficiency assessment of heat-generating equipment, distribution systems, and secondary energy resource utilization; (6) development of energy-saving recommendations. Metered parameters included natural gas (nm³), electrical energy (kWh), thermal energy output (Gcal), network make-up water volume (m³), and supply/return temperatures (°C).

2.6 Key Performance Indicators

- Boiler thermal efficiency (η , %): useful heat output / fuel energy input × 100
- Boiler plant thermal efficiency (η_{plant} , %): system-level ratio including auxiliary losses
- Network heat losses (Q_{loss} , % of heat generated at source)
- Network water make-up ratio relative to normative value
- Project-wide annual gas and electricity consumption change (%)

3. Results and discussion

3.1 Pre-Modernization Baseline

The gap between design-rated and operational performance at baseline was substantial across all parameters (Table 1). The temperature regime depression (design 150/70 °C vs. operational 60/50 °C) is analyzed as a mechanistically distinct finding in Section 3.2.

Table 1. K-1 “Yubileynaya” — Pre-modernization technical baseline

Parameter	Design / Rated	Operational (Pre-mod.)
Boiler type	PTVM-30	PTVM-30
Boiler thermal efficiency (η)	90%	83%
Plant thermal efficiency (η_{plant})	—	50–70%
Supply / return temperature	150/70°C	60/50°C
Total distribution network length	—	24,845 m
Above-ground / underground	—	13,194 / 11,681 m
Network heat losses	—	~ 40%
DHW availability	Year-round	~ 4 months/year
Network make-up ratio vs. normative	≤1.0×	1.54×
Residual insulation integrity	Full	Functionally destroyed

Table 2. Pre-modernization pumping equipment — K-1 “Yubileynaya”

Equipment	Model	Units	Flow (m ³ /h)	Head (m w.c.)	Power (kW/unit)
Network circulation pumps	SE 800/100	3	800	100	315
Make-up water pumps	D 320/50	3	320	50	75
Raw water pumps (set A)	D 320/50	1	320	50	75
Raw water pumps (set B)	D 350/71	1	350	71	75
Raw water pumps (set C)	D 315/71	1	315	71	75

Total installed network pump capacity: 945 kW (3×315 kW); fixed-speed operation.

3.2 Temperature Regime Depression: Mechanistic Finding

The operational supply/return temperature of 60/50 °C versus the design parameter of 150/70 °C represents a 60% reduction in the primary driving force for heat transfer. This was caused directly by the structural condition of building-level elevator nodes. In the open-circuit configuration, failure of a node allows primary network water — at temperatures potentially exceeding 95 °C — to enter consumer radiator circuits without attenuation. To eliminate this risk, the entire network was constrained to a temperature ceiling compatible with direct human exposure, which made efficient operation thermodynamically impossible. AITP installation resolved this constraint by hydraulically isolating all internal circuits from the primary network via plate heat exchangers, enabling primary-side temperature restoration to design parameters.

3.3 Post-Modernization Comparative Performance

Table 3 presents the full pre/post KPI comparison across all measured domains.

Table 3. Pre- vs. post-modernization KPI comparison

KPI	Pre-modernization	Post-modernization	Change
Boiler efficiency (η)	83%	92–95%	+9 to +12 pp
Plant thermal efficiency (η_{plant})	50–70%	92–95%	+22 to +45 pp
Network heat losses	~40%	15–20%	–20 to –25 pp
Annual gas savings (project-wide)	Baseline	–25–30%	≤ -320 M m ³ /yr
Annual electricity savings (project-wide)	Baseline	–15–20%	~–85 M kWh/yr
Network make-up water demand	1.54× norm.	–60–75% vs. baseline	Near normative
CO ₂ emissions (project-wide)	Baseline	–30%	—
DHW temperature at consumer	Seasonal/unstable	55–60°C	Year-round, 24 h/day
Consumer expenditure (mild months)	Baseline	–40% (est.)	Nov / Mar
Pipe service life	10–15 yr (residual)	30–50 yr (new)	×2 to ×4

Note: All values represent aggregate operational monitoring estimates from project documentation. Ranges reflect variation across the monitoring period. No confidence intervals are available; see Limitations. pp = percentage points.

3.4 Results Visualization

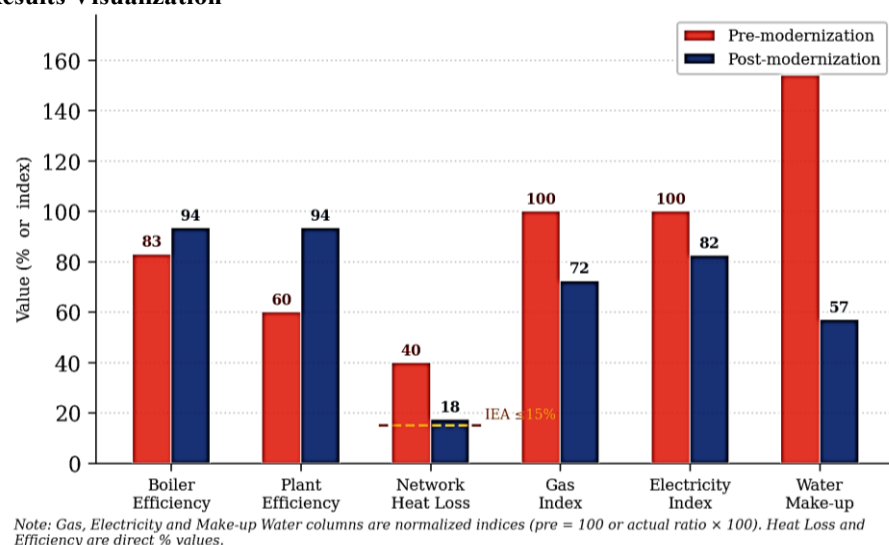


Fig.1. Pre- vs. Post-Modernization Key Performance Indicator Comparison. Gas, Electricity, and Make-up Water columns are shown as normalized indices (pre-modernization = 100). Efficiency and Heat Loss are direct percentage values. Dashed amber line indicates IEA benchmark for network heat loss ($\leq 15\%$).

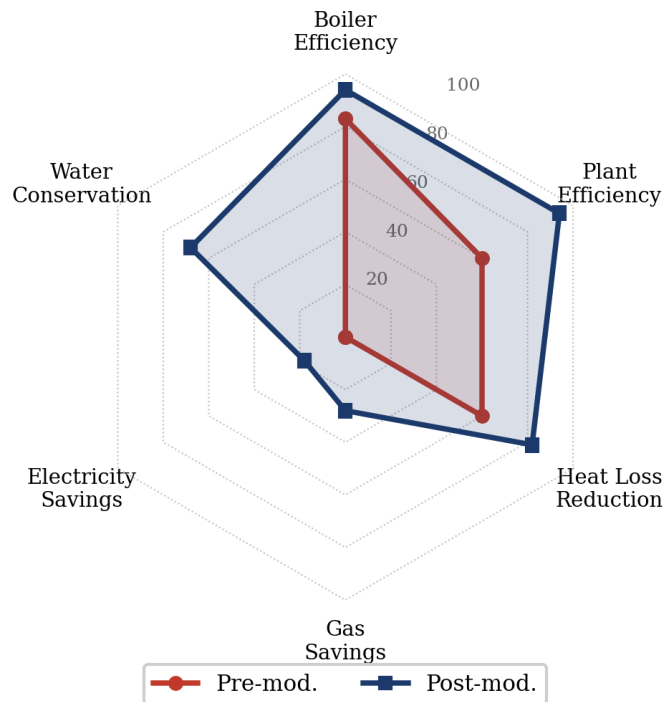


Fig.2. Multi-Domain Performance Radar: Pre- vs. Post-Modernization. All six axes are normalized to a 0–100 performance score. The Heat Loss axis is inverted (score = 100 – loss%). Consumption axes represent % reduction achieved (0 = no improvement at baseline).

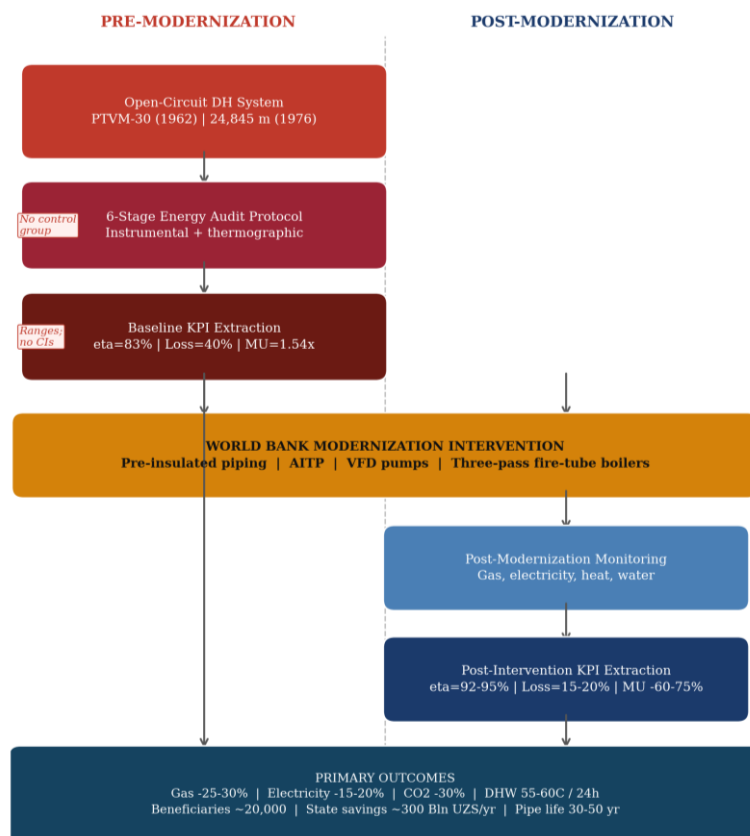


Fig.3. Study Design and Data Flow. Quasi-experimental pre/post case study structure showing the pre-modernization assessment phase, the World Bank modernization intervention, and the post-modernization monitoring and KPI extraction phases.



4. Discussion

4.1 Performance Against International Benchmarks

The post-modernization network heat loss of 15–20 % represents a 20–25 percentage point improvement over baseline but remains slightly above the IEA-recommended benchmark of ≤ 10 –15% for efficient DH systems [8] and typical European DH performance of 8–12% [5]. This residual gap is mechanistically expected: the Chirchik network serves a low-density, mid-rise (4–5 storey) building stock across a spread urban footprint — conditions that produce higher specific heat losses per unit of delivered energy than compact European DH zones. Boiler efficiency improvement from 83 % to 92–95% is consistent with published performance data for modern three-pass fire-tube boilers in this capacity class [9]. The below-rated pre-modernization performance of the PTVM-30 (83 % vs. 90 % rated) reflects degradation from extended operation without maintenance, a pattern documented across post-Soviet thermal energy infrastructure [3,4].

4.2 The Open-to-Closed Circuit Transition as the Central Mechanism

The architectural shift from open- to closed-circuit hydraulics, implemented through AITP plate heat exchanger isolation, is the single intervention that creates the conditions for all other efficiency gains. It removes the temperature ceiling imposed by open-circuit safety constraints. It eliminates primary-water extraction as the driver of make-up demand. It enables building-level demand-response automation. And it makes year-round DHW provision physically possible. This mechanism set is well-characterized in Northern European DH literature [6,7,10], but the Chirchik data represent one of the few documented quantitative monitoring datasets for this transition type in a Central Asian continental climate.

4.3 AITP vs. Elevator Node Connections

Elevator-node connections, the pre-modernization building-level interface, provide no load-response capability and impose the safety-driven temperature ceiling described above. AITP units replace this with automated outdoor-temperature-compensated control: the ECU adjusts heat delivery continuously to match ambient load. The documented 40% consumer expenditure reduction during mild heating months (November, March) reflects this capability — reducing heat input as outdoor temperatures rise above design-winter conditions rather than delivering a fixed output regardless of demand.

4.4 Pre-Insulated Pipe Technology: Co-Benefits

Beyond the quantified heat loss reduction, the polyurethane foam / high-density polyethylene pre-insulated pipe system delivers three additional benefits not captured in the primary KPIs: (I) a design service life of 30–50 years versus 10–15 years for the steel pipes being replaced, most of which had already exceeded their design life; (II) chemical inertness of the polyethylene casing, eliminating soil contamination from degrading glass wool and bitumen insulation of the original 1976 network; (III) elimination of noise from vibrating aged above-ground pipe sections in residential areas.

4.5 Scalability and Policy Context

ChIE operates 15 boiler stations across Chirchik; K-1 was the pilot. If comparable efficiency gains are achieved across the remaining 14 stations — a projection supported by consistent outcomes in the parallel Bukhara implementation — aggregate resource savings would scale proportionally. Government Resolution No. 306 (2019, amended 2023) and Presidential Decree No. PP-118 (2023) establish the regulatory framework for this scaling. State-level savings are estimated at approximately 300 billion Uzbekistani sum per year from reduced energy resource consumption.

5. Limitations and Conclusion

5.1 Limitations

Single-facility design. This study reports on one boiler station. Generalization to the remaining 14 ChIE stations and to other cities requires verification against station-specific baseline data.

Absence of a control group. No matched unreformed DH system was available for parallel comparison. Observed performance changes are attributed to the modernization intervention based on engineering logic and monitoring data; confounders including inter-annual variation in heating degree-days and changes in connected building occupancy are uncontrolled.

Aggregate monitoring estimates without confidence intervals. All KPI values are presented as operational ranges reflecting the nature of the source data — aggregate energy audit records — not an analytical choice.

Incomplete temporal metadata. The exact duration of the pre- and post-comparison monitoring periods was not specified in available project documentation, preventing normalization of consumption data to heating degree-days.

5.2 Conclusion

The transition of the K-1 “Yubileynaya” boiler station and its distribution network in Chirchik, Uzbekistan, from an open-circuit hot-water scheme with Soviet-era infrastructure to a closed-circuit



system with pre-insulated piping and AITP-based building connections produced documented improvements across all monitored performance domains. Boiler efficiency increased from 83% to 92–95%. Network heat losses decreased from ~ 40% to 15–20%. Annual natural gas demand declined by 25–30%, electricity demand by 15–20%, and network water replenishment by 60–75%. CO₂ emissions fell by approximately 30%. Consumer-level outcomes included year-round DHW provision at 55–60°C and expenditure reductions of up to 40% during transitional heating months. The direct beneficiary population numbers approximately 20,000 residents. These results confirm that the open-to-closed circuit transition with AITP and pre-insulated pipe deployment produces substantial, simultaneous gains in thermal, hydraulic, electrical, and environmental efficiency in a post-Soviet Central Asian district heating system, and provides a quantified operational reference for analogous reform programs across the region.

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