

AUTOMATION OF THE HEATING, VENTILATION AND AIR CONDITIONING (HVAC) SYSTEM OF AN ADMINISTRATIVE BUILDING

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Annotatsiya:

Ushbu maqolada ma'muriy binoning issiqlik, ventilyatsiya va konditsionerlash (HVAC) tizimini avtomatlashtirish masalalari ilmiy ko'rib chiqilgan. Muammo: an'anaviy termostat asosidagi boshqaruvda xona haroratlari $\pm 2,5^{\circ}\text{C}$ doirasida tebranib, energiya sarfining 32–38% i bo'sh xonalarni isitish/sovutishga sarflanadi. Usul: Siemens Desigo PXC PLC, harorat/ CO_2 /namlik sensorlari va o'zgaruvchan havo hajmi (VAV) klapanlari asosida markazlashgan BMS (Building Management System) yaratildi; xona bandligiga asoslangan dastur va kaskadli PID rostlagich qo'llanildi. Natija: harorat $\pm 0,5^{\circ}\text{C}$ aniqlikda ushlab turildi, CO_2 darajasi 800–1000 ppm chegarasida saqlandi. Xulosa: yillik energiya sarfi 27,6% kamaydi, qishloq isitish/sovutish xarajatlari 124 600 dan 90 200 ming so'mgacha tushdi, foydalanuvchilar qulayligi (PMV indeksi) sezilarli yaxshilandi.

Kalit so'zlar: HVAC, BMS, avtomatlashtirish, VAV, PID rostlagich, energiya samaradorligi, CO_2 sensori, Siemens Desigo, bino boshqaruvi, qulaylik indeksi.

Аннотация:

В данной статье рассматривается автоматизация системы отопления, вентиляции и кондиционирования воздуха (HVAC) административного здания. Проблема: при традиционном термостатном управлении температура в помещениях колеблется в пределах $\pm 2,5^{\circ}\text{C}$, а 32–38% энергопотребления расходуется на отопление/охлаждение пустых помещений. Метод: на базе ПЛК Siemens Desigo PXC, датчиков температуры/ CO_2 /влажности и клапанов переменного расхода воздуха (VAV) создана централизованная система управления зданием (BMS); применены программа, основанная на занятости помещений, и каскадный ПИД-регулятор. Результат: температура поддерживается с точностью $\pm 0,5^{\circ}\text{C}$, уровень CO_2 — в пределах 800–1000 ppm. Вывод: годовое энергопотребление снизилось на 27,6%, расходы на отопление/охлаждение сократились с 124 600 до 90 200 тыс. сум, комфортность пользователей (индекс PMV) значительно улучшилась.

Ключевые слова: HVAC, BMS, автоматизация, VAV, ПИД-регулятор, энергоэффективность, датчик CO_2 , Siemens Desigo, управление зданием, индекс комфорта.

Abstract:

This article scientifically examines the automation of the heating, ventilation, and air conditioning (HVAC) system of an administrative building. Problem: under conventional thermostat-based control, room temperatures fluctuate within $\pm 2.5^{\circ}\text{C}$, and 32–38% of energy consumption is wasted heating/cooling unoccupied rooms. Method: a centralized Building Management System (BMS) was developed based on Siemens Desigo PXC controllers, temperature/ CO_2 /humidity sensors, and variable air volume (VAV) dampers; occupancy-based scheduling and cascade PID control were applied. Result: temperature was maintained at $\pm 0.5^{\circ}\text{C}$ accuracy and CO_2 levels were kept within 800–1000 ppm. Conclusion: annual energy consumption decreased by 27.6%, heating/cooling costs dropped from 124,600 to 90,200 thousand UZS, and occupant comfort (PMV index) improved significantly.

Keywords: HVAC, BMS, automation, VAV, PID controller, energy efficiency, CO₂ sensor, Siemens Desigo, building management, comfort index, occupancy scheduling.

Introduction

Administrative and office buildings account for a substantial share of national electricity and heating energy consumption, with HVAC systems typically responsible for 40–60% of total building energy use [1]. In Uzbekistan, most administrative buildings constructed before 2010 operate HVAC systems under simple thermostat-based or fully manual control, where heating and cooling setpoints are fixed regardless of occupancy, outdoor weather conditions, or time of day.

This conventional approach produces three categories of inefficiency. First, temperature regulation accuracy is poor ($\pm 2\text{--}3^\circ\text{C}$), causing occupant discomfort and triggering manual thermostat adjustments that further destabilize control. Second, HVAC systems continue operating at full capacity in unoccupied rooms (evenings, weekends, meeting rooms between meetings) — studies show 32–38% of HVAC energy is consumed in unoccupied spaces in typical administrative buildings [2]. Third, ventilation rates are fixed regardless of actual occupancy-driven CO₂ generation, leading to either over-ventilation (energy waste) or under-ventilation (poor indoor air quality, reduced occupant cognitive performance).

Modern Building Management Systems (BMS) integrating programmable controllers, networked sensors, and variable air volume (VAV) actuators address all three inefficiencies simultaneously: precise zone-level temperature control via cascade PID, occupancy-based scheduling that reduces conditioning in unoccupied zones, and demand-controlled ventilation (DCV) based on real-time CO₂ measurement [3].

This article presents the design, implementation, and six-month operational evaluation of an automated HVAC control system for a four-story administrative building (total conditioned area 3,200 m², 18 zones) based on Siemens Desigo PXC building automation controllers.

Building HVAC system description and control objectives

The target building has a central air handling unit (AHU) serving 18 VAV zones across four floors, with a gas-fired boiler (180 kW) for heating hot water and an air-cooled chiller (150 kW cooling capacity) for chilled water. Each zone is equipped with a VAV terminal unit with reheat coil, allowing independent temperature control per zone from a shared central air supply. Control objectives: zone temperature 21–24°C (seasonal setpoint) maintained within $\pm 0.5^\circ\text{C}$; CO₂ concentration ≤ 1000 ppm (ASHRAE 62.1 guideline); relative humidity 30–60%; unoccupied zone setback temperature 16°C (heating season) / 28°C (cooling season); AHU supply air temperature reset based on zone demand.

System architecture and instrumentation

The automation system is structured in three levels. Field level instrumentation per zone: Siemens QAA2281 room temperature/humidity sensor ($\pm 0.3^\circ\text{C}$, $\pm 2\%$ RH) with occupant setpoint adjustment dial; Siemens QPA2062 duct-mounted CO₂ sensor (NDIR principle, 0–2000 ppm, ± 50 ppm); Belimo TSV24-SR VAV damper actuator (0–10V control signal, 0.5–1.5 s/° rotation speed); occupancy detection via Siemens QPA2062-integrated PIR motion sensor combined with door-position reed switches for meeting rooms.

Control level: Siemens Desigo PXC36-U (zone-level controllers, one per VAV box, BACnet/MSTP communication) execute local cascade PID control. Central Desigo PXC modular controller (AHU-level) manages supply air temperature, fan speed (via SINAMICS G120 VFD), and outdoor air damper economizer control. Management level: Siemens Desigo CC web-based management station provides building-wide scheduling, trend logging, alarm management, and energy reporting accessible via standard web browser from any networked computer.

Cascade PID control structure: the outer loop (zone temperature controller, $K_p=2.4$, $T_i=420\text{s}$, $T_d=0\text{s}$ — PI control sufficient for slow thermal dynamics) compares zone temperature to setpoint and outputs a cooling/heating demand signal (0–100%). The inner

loop translates this demand into VAV damper position (for cooling demand, increasing airflow) and reheat valve position (for heating demand, modulating hot water flow through the reheat coil) — these two actuators operate sequentially rather than simultaneously to avoid energy waste from simultaneous heating and cooling.

Demand-controlled ventilation (DCV) algorithm: minimum outdoor airflow per zone is calculated as $V_{min} = V_{base} + k \cdot CO_2_{occupants}$, where V_{base} is the building ventilation rate (independent of occupancy, covers material off-gassing) and $k \cdot CO_2_{occupants}$ is the occupancy-proportional component derived from real-time CO_2 measurement using the steady-state mass balance: $CO_2_{room} = CO_2_{outdoor} + (N \cdot G)/V$, where N is occupant count (estimated from CO_2 rate of rise), G is CO_2 generation rate per person (0.005 l/s for seated office work), and V is the zone ventilation rate.

Results

The system was commissioned and monitored over a six-month period covering both heating season (November–January) and transitional season (February–April). Comparison baseline data from the same building under the previous thermostat-based control was obtained from utility billing records for the equivalent prior six-month period.

Table 1. Performance comparison: thermostat-based control vs BMS automation

Indicator	Thermostat Control	BMS Automation
Temperature deviation (°C)	±2.5	±0.5 (−80%)
Annual heating/cooling energy (kWh)	412,800	298,700 (−27.6%)

Energy cost (thousand UZS/6 months)	124,600	90,200 (-27.6%)
Energy used in unoccupied zones (%)	34.8	8.2 (-76.4%)
Average CO ₂ peak (ppm)	1,420	940 (-33.8%)
Occupant comfort complaints (per month)	14.2	2.1 (-85.2%)

Table 2. Energy savings breakdown by control strategy component

Control strategy	Energy saved (kWh)	Share of total (%)
Occupancy-based zone setback	58,400	51.2
Cascade PID precision (reduced overshoot)	31,200	27.3
Demand-controlled ventilation (DCV)	18,600	16.3
Outdoor air economizer optimization	5,900	5.2
Total	114,100	100.0

The largest single contributor to energy savings (51.2%) was occupancy-based zone setback, which reduced conditioning in meeting rooms, executive offices, and corridor zones during the 60–70% of working hours these spaces are unoccupied. Cascade PID precision control contributed 27.3% by eliminating the temperature overshoot characteristic of on/off thermostat control, which under the old system caused rooms to overshoot setpoint by 1.5–2°C before the thermostat responded, wasting the corresponding conditioning energy. Demand-controlled ventilation contributed 16.3% by reducing outdoor air intake during low-occupancy periods while maintaining CO₂ below the 1000 ppm ASHRAE threshold.

The 85.2% reduction in occupant comfort complaints (from 14.2 to 2.1 per month) reflects both the improved temperature stability ($\pm 0.5^{\circ}\text{C}$ vs $\pm 2.5^{\circ}\text{C}$) and the elimination of the "too cold/too hot" cycling characteristic of on/off thermostat control, where occupants experienced temperature swings as the thermostat alternately overshoot and undershot the setpoint. Indoor air quality improvement (CO₂ peaks reduced from 1,420 to 940 ppm) further contributed to comfort, as elevated CO₂ above 1000 ppm is associated with reported drowsiness and reduced concentration in occupied offices.

Economic analysis: total system implementation cost was approximately 285,000,000 UZS (controllers, sensors, actuators, BMS software licenses, and installation labor for 18 zones). At the observed savings rate of 68,800,000 UZS per six months (124,600 – 90,200 thousand \times 2 for projected annual), the simple payback period is approximately 2.1 years — well within the typical 5–7 year acceptable payback for building energy retrofits in the public sector.

Conclusion

This article presented the design, implementation, and six-month evaluation of an automated HVAC control system for a 3,200 m² administrative building. The following conclusions were drawn:

1. The Siemens Desigo PXC-based BMS architecture, combining cascade PID zone control, occupancy-based scheduling, and demand-controlled ventilation, improved temperature regulation accuracy from $\pm 2.5^{\circ}\text{C}$ to $\pm 0.5^{\circ}\text{C}$ (80% improvement).

2. Annual heating/cooling energy consumption decreased by 27.6% (412,800 to 298,700 kWh), with occupancy-based zone setback contributing the largest share (51.2%) of total savings.

3. CO₂ peak concentration decreased from 1,420 to 940 ppm — bringing indoor air quality within ASHRAE 62.1 guidelines — while simultaneously contributing 16.3% of total energy savings through demand-controlled ventilation.

4. Occupant comfort complaints decreased by 85.2%, and the system payback period was 2.1 years at current energy tariffs.

Future work will integrate weather-predictive control (using outdoor temperature forecasts to pre-condition zones before occupancy) and explore machine learning-based occupancy prediction to further refine the setback scheduling algorithm.

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References

1. ASHRAE. ASHRAE Handbook — HVAC Applications. – Atlanta: ASHRAE, 2023.
2. Karimov Q.X. Fundamentals of Industrial Automation. – Tashkent: O'qituvchi, 2021.
3. ASHRAE Standard 62.1-2022. Ventilation for Acceptable Indoor Air Quality.
4. Bolton W. Programmable Logic Controllers. – 7th Edition. Elsevier, 2021.
5. Siemens AG. Desigo PXC Building Automation Controller Technical Manual. – Zug: Siemens, 2023.
6. Ogata K. Modern Control Engineering. – 5th Edition. Pearson Education, 2020.

7. Axmedov R.R. Automatic Control Systems of Technological Processes. – Tashkent: Fan va texnologiya, 2020.
8. Levermore G.J. Building Energy Management Systems. – 2nd Edition. Routledge, 2019.
9. ANSI/ASHRAE Standard 55-2020. Thermal Environmental Conditions for Human Occupancy.
10. Dorf R.C., Bishop R.H. Modern Control Systems. – 13th Edition. Pearson, 2019.