Pathway towards an efficient use of local natural resource

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Project "Pathway to the efficient use of local natural resources"

Energy Efficiency Renovation and Air Quality

Kindergarten, Milot

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Introduction

Renovating a kindergarten to improve energy efficiency not only reduces operational costs and environmental impact but also enhances the health, safety, and comfort of its occupants—especially young children. Poorly insulated buildings with outdated heating systems (such as wood stoves) often suffer from suboptimal indoor air quality (IAQ), which can negatively affect children's health and cognitive development. This report examines key IAQ parameters—carbon dioxide (CO_2), carbon monoxide (CO), temperature, and humidity—and evaluates how implementing energy efficiency measures can improve these conditions.

Climate Characteristics:

In the territory of the Kurbin district, the Mediterranean climate prevails, fertile plains, low hills, mountain ranges with altitudes over 700 meters above sea level, and dense forests. The Mediterranean climate, with hot and dry summers and mild, cool winters, is typical for the plains and hilly areas, while in the mountainous areas, snow falls during winter. The average snow depth reaches about 50 cm. A characteristic feature of every season of the year is the strong winds that blow from the northeast and east, directed through natural corridors and mountain slopes. As a result of the rising level of the Mat River's bed due to the construction of hydroelectric basins, wind speeds can reach up to 100 km/h, especially during the winter period.

From a temperature standpoint, there are large fluctuations between winter and summer. The average annual temperature is 15.6°C, while the average amplitude is 18°C. Rainfall in the municipality's territory is unevenly distributed. The average annual rainfall is 1350 mm. In the mountainous areas, mainly where snow falls in winter, rainfall is also present during the summer, while in the hilly and plain areas, summer is dry. Sunny days range from 220 to 240 days, with an annual average of up to 3000 hours of sunshine.

1. Technical Analysis of Pre-Renovation Inefficiencies

1.1.Inadequate or Nonexistent Thermal Insulation

Construction Details:

- The building envelope lacked insulation in exterior walls, attic, and floor slab. Likely U-values were >1.5 W/m²K for walls and >2.0 W/m²K for windows—well above modern energy codes.
- Heat transfer was dominated by **conduction** through uninsulated surfaces and **air infiltration** through joints and gaps.

Implications:

- In winter, heat generated indoors rapidly escapes, requiring constant heating input.
- In summer, radiant heat gains from the roof and walls increase internal temperatures.
- **Thermal bridges** (e.g. at floor-wall junctions or window frames) created cold surfaces, increasing risk of condensation and mold.
- Children sitting near exterior walls or windows likely experienced **thermal asymmetry**, leading to discomfort, distraction, or illness.

Why it matters in kindergartens:

- **Young children are more sensitive to temperature fluctuations** due to their underdeveloped thermoregulation systems.
- Cold surfaces (walls, floors) increase the risk of respiratory illness and discomfort—especially when children spend time playing or sitting on the floor.
- Lack of insulation leads to **unpredictable indoor temperatures**, which affects learning, concentration, and mood regulation in young children.

1.2.Inefficient Windows and High Air Leakage

Construction Details:

- Single-glazed windows with aluminum or decayed wood frames.
- High **U-values (~5.0–6.0 W/m²K)** and poor air-tightness (no compression seals or thermal breaks).
- Air changes per hour (ACH) at 50 Pa likely exceeded 8–10 ACH.

Implications:

- Convective heat loss from cold glass surfaces caused downdrafts and cold zones near windows.
- Cold radiation from windows reduced **mean radiant temperature (MRT)**, making rooms feel colder than measured air temperature.
- Frequent drafts and pressure imbalances reduced heating efficiency and comfort.
- **Uncontrolled air infiltration** (stack effect, wind-driven) made temperature regulation impossible, especially during storms or cold snaps.

Why it matters in kindergartens:

- Children often play near windows, where **cold downdrafts** and **temperature asymmetry** are most noticeable.
- High air leakage disrupts stable classroom conditions, forcing frequent manual adjustments to heating and ventilation.
- Drafts and poor airtightness reduce not only comfort but also **security and noise insulation**, which are vital for a calm, focused learning environment.

1.3. Wood Stove Heating: Outdated and Hazardous

System Description:
- Traditional solid-fuel stoves manually fed with wood or biomass.
- No thermostatic control, uneven heat distribution, and open combustion.

Technical Risks:
- Incomplete combustion emitted **CO (carbon monoxide)**, a colorless and odorless gas with serious health risks.
- **Particulate Matter (PM2.5)** was released indoors, penetrating deep into lungs—especially harmful for children.
- Stoves provided localized heat, leading to **thermal zoning** (hot near the stove, cold elsewhere).
- Excess heat near stoves could exceed 26–28°C, while zones farther from the stove dropped below 18°C.
- Wood-burning required continuous maintenance, creating **inconsistent heat supply**.

Health Implications:
- CO exposure above **9 ppm average (8-hour)** or **35 ppm for 1 hour** violates WHO guidelines and could cause headaches, dizziness, or worse.
- Particulate exposure exacerbates asthma and weakens immune responses in young children.

Why it matters in kindergartens:

- **Carbon monoxide (CO)** is extremely dangerous for children, whose smaller lungs absorb toxins faster. Even low CO exposure can impair cognitive development.
- Open stoves pose **burn risks** and require manual fueling, which may be unsafe around curious or unsupervised children.
- Uneven heating (hot near stove, cold across the room) is not compatible with group learning or structured classroom zones.
- Air pollution from stoves worsens **asthma**, allergies, and other respiratory issues—prevalent in young children.

1.4.Lack of Mechanical Ventilation

Ventilation Strategy:
- Reliance on passive ventilation via window opening or infiltration.
- No heat recovery, filtration, or demand control.

CO_2 Accumulation:
- In occupied rooms (e.g. 20+ children + adults), human respiration emits **~20 liters/hour CO_2 per person**.
- Without ventilation, CO_2 levels easily exceeded 2,000 ppm within 30–60 minutes.
- High CO_2 correlates with fatigue, reduced concentration, slower task performance, and headaches in children.

Stale Air & Humidity:
- Poor air exchange meant pollutants (VOCs, allergens, moisture, odors) accumulated.
- In winter, RH% often dropped below 25% → dry skin, eye irritation, airborne virus survival.
- In spring/summer, RH% could rise above 65–70%, increasing mold risk in corners and on cold surfaces.

Thermal Load Impacts:

- Window opening for ventilation caused **thermal shocks** (loss of warm air in winter or cool air in summer), increasing energy demand.

Why it matters in kindergartens:

- Children exhale more **CO_2 per kilogram of body weight** than adults, and they spend long hours in the same room. Without ventilation, CO_2 builds up fast.
- Elevated CO_2 (>1,500 ppm) is linked to **drowsiness, inattention, and irritability**, which can disrupt group activities and emotional regulation.
- Natural ventilation via windows often doesn't happen during winter (too cold) or summer (too hot), leading to **chronically poor air quality**.
- Many children are especially vulnerable to indoor pollutants, allergens, or mold, due to **developing immune systems**.

1.5.Indoor Humidity Instability and Mold Risk

Moisture Generation:

- Children, staff, cleaning, and cooking produce significant moisture.
- Without exhaust systems or humidity control, vapor accumulates in enclosed spaces.

Dry Air (Winter):

- Heating without humidification drops RH below 30%.
- Leads to **dry mucous membranes**, which increases risk of colds and respiratory infections.

High Humidity (Summer/Spring):

- RH over 60% in warm conditions can lead to **condensation** on thermal bridges (window corners, poorly insulated walls).
- Supports **fungal growth**, leading to mold, allergic reactions, and long-term structural damage.

Why it matters in kindergartens:

- Low humidity (<30%) leads to **dry throats, irritated eyes, and cracked skin**, making children uncomfortable and more vulnerable to colds.
- High humidity (>65%) promotes **mold growth**, which can exacerbate asthma and allergies, already common in early childhood.
- Children often sit or crawl near floor-level where **mold spores** and **condensate** accumulate.
- Inconsistent humidity also affects **wood furniture, toys, and learning materials**, shortening their lifespan and hygiene quality.

2. Measuring Air Quality

2.1.Methodology:

This section outlines the methodology used to measure key IAQ indicators—**temperature, relative humidity (RH), carbon dioxide (CO_2), and carbon monoxide (CO)**—before and after renovation. These indicators were selected due to their direct impact on comfort, cognition, health, and safety, particularly for young children.

2.2. Measurement Locations and Timing

- **Classroom Selection**: Representative classrooms were selected, prioritizing those with:
    - High occupancy
    - Varying exposure (e.g., sun-facing vs. shaded sides)
    - Past complaints or known issues
- **Sensor Placement**:
    - Mounted at **child breathing height** (typically 0.6–1.1 m above floor)
    - Away from direct heat sources, windows, or doors
- **Time Intervals**:
    - Data logged at **1–5 minute intervals**, continuously over at least **7 consecutive days**, capturing:
        - Full occupancy cycles
        - Night-time and weekend baselines
        - Outdoor weather influences

2.3.Instruments and Calibration

PARAMETER	INSTRUMENT TYPE	ACCURACY	CALIBRATION
TEMPERATURE	Digital thermistor or RTD	±0.5°C	Factory-calibrated, cross-checked with reference thermometer
RELATIVE HUMIDITY	Capacitive or resistive RH sensor	±3% RH	Pre- and post-measurement zeroing
CO_2	NDIR (Non-Dispersive Infrared) sensor	±50 ppm or ±3%	Calibrated with fresh outdoor air or gas reference
CO	Electrochemical sensor	±2 ppm or ±5%	Calibrated using certified gas standard

2.4. Measurement Conditions

- **Occupied Hours (Key Focus)**:
    - Data was analyzed specifically during hours when children and staff were present.
    - CO_2 peaks were typically used to assess ventilation adequacy.

2.5. Analysis Metrics

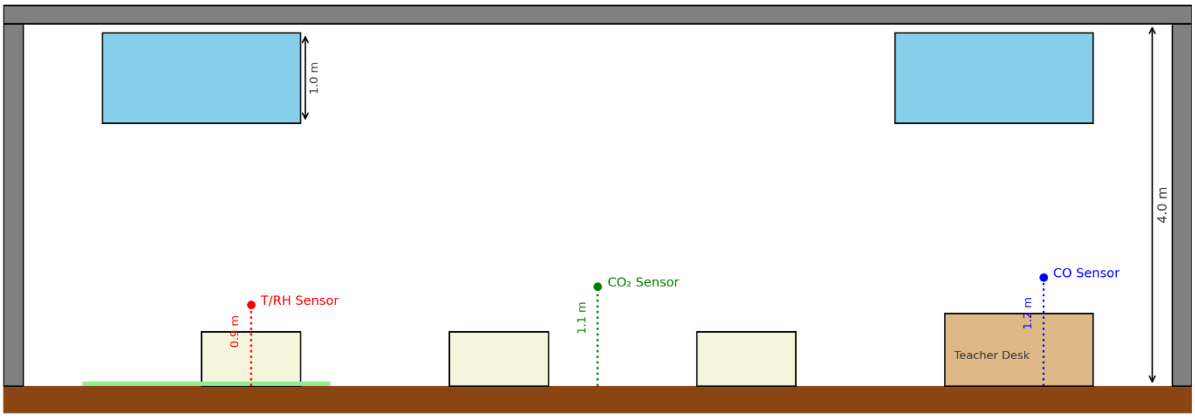
- **CO_2**:
    - Baseline: ~400–450 ppm (outdoor)
    - Target: <1000 ppm (per EN 16798-1 Category II)
    - Short-term peaks tolerated up to 1500 ppm, not exceeding 15-minute average
- **CO**:
    - Max: 9 ppm (8-hour average), 35 ppm (1-hour average), per WHO and OSHA
    - Zero-tolerance for sustained levels >5 ppm in classrooms
- **Temperature**:
    - Optimal comfort range: 20–22°C during heating season
    - Variability assessed via standard deviation and thermal mapping

- **Relative Humidity**:
  - Target range: 40–60% RH
  - Measured to detect risks of dryness (<30%) or mold (>65%)

2.6.Occupant Feedback (Optional but Valuable)

- Short teacher/staff surveys or interviews were used to **correlate sensor data with perceived comfort or complaints**.
- a standard comfort scale (ASHRAE 7-point scale or visual analog scale for simplicity).

Side View: Sensor Placement with Height Measurements



3. Testing devices used in the case of Milot Kindergarten :

1- TESTO Brand Air Quality Meter
Model 160 AQI WIFI

Be sure. testo

Ordering data Wi-Fi data loggers

testo 160 IAQ

testo 160 IAQ Wi-Fi Data Logger with display and integrated sensors for temperature, humidity, CO_2 and atmospheric pressure

Order no. 0572 2014

Temperature measurement	
Measuring range	32 to 122 °F (0 to +50 °C)
Accuracy	± 0.9 °F (± 0.5 °C)
Resolution	0.1 °F (0.1 °C)
Humidity measurement	
Measuring range	0 to 100 %RH (non-condensing)
Accuracy	±2 %RH at 77 °F (+25 °C) and 20 to 80 %RH ±3 %RH at 77 °F (+25 °C) and < 20 %RH and > 80 %RH ±1 %RH hysteresis ±1 %RH / year drift
Resolution	0.1% RH
CO_2 measurement	
Measuring range	0 to 5,000 ppm
Accuracy	±(50 ppm + 3 % of m.v.) at 77 °F (+25 °C) Without external power supply: ±(100 ppm + 3 % of m.v.) at 77 °F (+25 °C)
Resolution	1 ppm
Pressure measurement	
Measuring range	600 to 1100 mbar
Accuracy	±3 mbar at 71.6 °F (+22 °C)
Resolution	.40 inH20 (1 mbar)
WLAN	
Standard	802.11 b/g/n
Security	WPA2 Enterprise: EAP-TLS, EAP-TTLS-TLS, EAP-TTLS-MSCHAPv2, EAP-TTLS-PSK, EAP-PEAP0-TLS, EAP-PEAP0-MSCHAPv2, EAP-PEAP0-PSK, EAP-PEAP1-TLS, EAP-PEAP1-MSCHAPv2, EAP-PEAP1-PSK, WPA Personal, WPA2 (AES), WPA (TKIP), WEP
General	
Operating temperature	32 to 122 °F (0 to +50 °C)
Storage temperature	32 to 122 °F (0 to +50 °C)
Protection class	IP20
Measuring cycle	Dependent on Cloud licence Basic: 15 min to 24 h Advanced: 1 min to 24 h
Communication cycle	Dependent on Cloud licence Basic: 15 min to 24 h Advanced: 1 min to 24 h
Memory	32,000 readings (sum of all channels)
Voltage supply (alternatively, power via USB connection)	4 x AA alkaline batteries 1.5 V
Battery life (depending on the measuring and communication cycle through the Cloud)	1 year
Dimensions	4.6 x 3.23 x 1.26 in. (117 x 82 x 32 mm)
Weight (including batteries)	0.6 lbs. (269 g)

Accessories

	Order no.
Deco-cover for testo 160 IAQ	0554 2012
Wall bracket for testo 160 IAQ	0554 2015
Alkaline AA batteries up to -14 °F (-10 °C) (pack of 4)	0515 0414
External USB power supply	0572 2020
ISO calibration certificate temperature -17.6 °F, 32 °F, 104 °F (-8 °C, 0 °C, +40 °C)	0520 0171
ISO calibration certificate humidity at 77 °F (+25 °C), humidity points 11.3 %RH and 75.3 %RH	0520 0076
ISO calibration certificate CO_2, calibration points 0; 1000; 5000 ppm	0520 0033

2. Second metering device was a Handheld CO meter:

testo 315-4

Be sure. testo

CO measuring instrument testo 315-4

testo 315-4

testo 315-4, CO measuring instrument
incl. USB mains unit and cable

Order no. 0632 3155

The testo 315-4 is a convenient, precise and robust measuring instrument for recording ambient CO values. It identifies even the slightest concentrations of the highly toxic gas. This allows you to safely judge whether, e.g. ambient air-dependent heating systems can be operated without danger.

- TÜV-tested according to EN 50543
- Electrochemical CO sensor for reliable and highly precise measurement results
- Optical and audible alarm when limit values are exceeded (freely adjustable limit values)
- Printout of measurement data possible directly on site

General technical data

Storage temperature	-20 to +60 °C / -4 to +140 °F
Operating temperature	0 to +40 °C / +32 to +104 °F
Operating humidity	0 tp 95 %RH
Protection class	IP40 acc. to EN 60529
Power supply	Lithium-polymer battery pack
Battery life	50 h measuring time (at +20 °C / +68 °F) / Mains operation possible
Battery charging	In the instrument via mains unit
Interface	IRDA interface
Approval	In accordance with EN 50543
EC Directive	2014/30/EU
Dimensions	190 x 65 x 40 mm

Sensor type	Measuring range	Accuracy (± 1 digit)	Resolution
CO sensor	0 to 100 ppm	±3 ppm (0 to 20 ppm) ±5 ppm (> 20 ppm)	0.5 ppm
Temperature/humidity module	+5 tp +95 %RH -10 to +60 °C / 14 to +140 °F	±2.5 %RH (5 to 95 %RH) ±0.5 °C (±1 digit) / ±32.9 °F (±1 digit)	0.1 %RH 0.1 °C / 0.1 °F

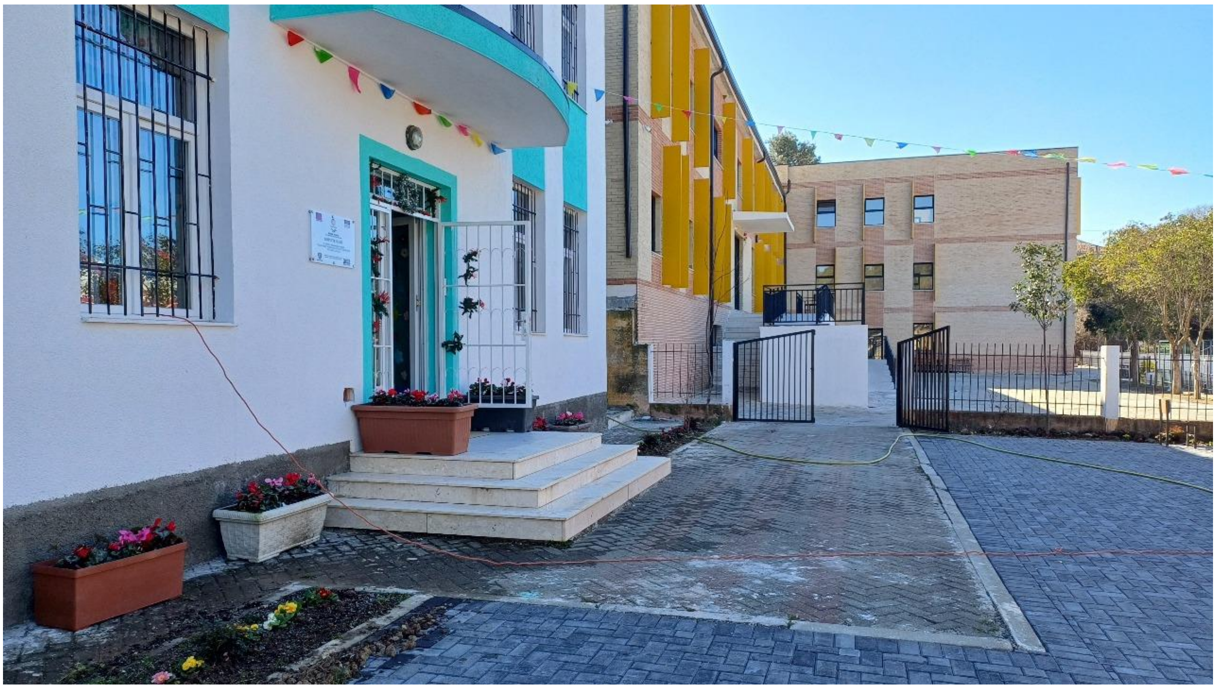
Measuring instrument accessories	Order no.
Temperature/humidity module Ø 25 mm, plug-in	0636 9725
USB mains unit incl. cable	0554 1105
TopSafe testo 315-4	0516 0221
Bag for safe storage of the measuring instrument	0516 0191
Testo IRDA printer with wireless infrared interface, 1 roll of thermal paper and 4 AA batteries	0554 0549
Spare thermal paper for printer, permanent ink	0554 0568
Control and calibration set for humidity sensors (11.3% RH and 75.3% RH)	0554 0660

4. Situation after the renovation:

The following renovations and works have been conducted at the kindergarten:

NO.	WORKS	UNIT	QUANTITY
1	Works for preparation of floor insulation	m3	10
2	Floor leveling concrete layer	m3	6
3	Hydro insulation / 2 layers	m2	360
4	PV solar panels	cope	1
5	Insulation of walls with polyurethane and respective insulation layers	m2	360
6	PV heating cooling system	cope	1
7	Works preparation for ceiling	m2	300
8	Wall and ceiling plaster	m2	300
9	Electrical installations, plugs, switches	cope	1
10	Parquet flooring layer	cope	1
11	Painting - First quality	cope	1
12	Works for preparation of floor insulation	cope	1
13	Floor leveling concrete layer	m2	800

4.1.Below we can find some pictures of after the renovation:




ecotherm
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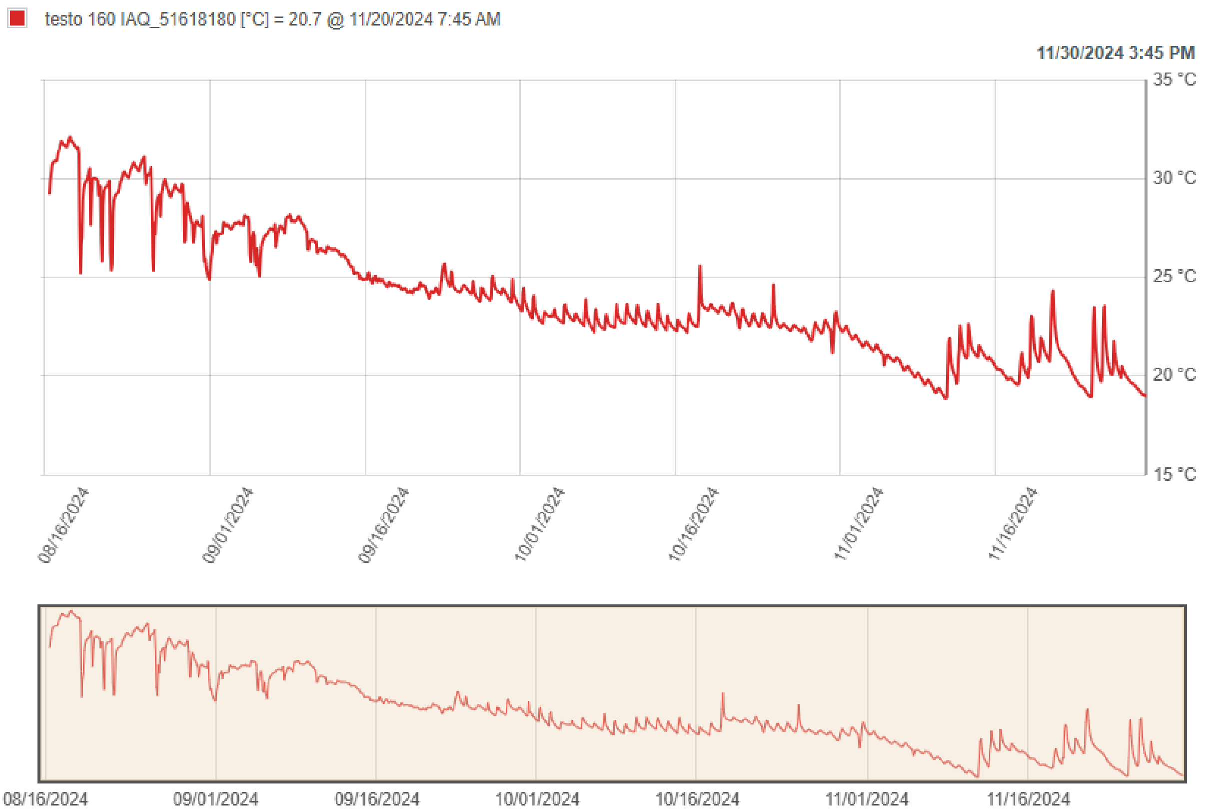
5. Measurements from the Testo Devices:

5.1. Temperature in Degrees Celcius



6.1 Interpretation of the Temperature Graph (Post-Renovations)

The provided graph shows the temperature over a period from August 16, 2024, to November 16, 2024 , measured in degrees Celsius (°C). The data was recorded using a testo 160 IAQ sensor , and the highest recorded temperature is 20.7°C at 7:45 AM on November 20, 2024 . This graph represents the indoor environment after energy efficiency renovations , highlighting significant improvements compared to the pre-renovation conditions.

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1. Key Features of the Graph

- X-axis : Represents time, spanning from August 16, 2024, to November 16, 2024.
- Y-axis : Represents temperature in °C, ranging from approximately 15°C to 35°C .
- Data Trend : The graph shows fluctuations in temperature over time, with noticeable peaks and troughs. However, these fluctuations are now more controlled and within a comfortable range compared to before the renovations.

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2. Observations

2.1 Overall Pattern

- The graph displays a general downward trend in temperature as the seasons transition from summer to fall/winter. This reflects the natural seasonal changes, but the indoor environment now maintains a more stable and comfortable temperature range due to the renovations.
- There are frequent fluctuations in temperature, indicating regular adjustments by the HVAC system to maintain optimal conditions. These fluctuations are much smaller and more manageable compared to the pre-renovation period.

2.2 Peaks

- High Temperatures : Several spikes are visible throughout the graph, particularly in August and September, where temperatures briefly exceed 28°C–30°C .
    - While these peaks are still present, they are significantly lower and less frequent than before the renovations. Prior to the upgrades, temperatures likely exceeded 35°C or higher during peak periods.
    - The reduction in peak temperatures indicates improved cooling capabilities, better insulation, and more efficient ventilation systems.

2.3 Troughs

- Low Temperatures : The troughs represent times when temperatures were relatively low, often below 20°C .
    - In October and November, temperatures stabilize around 20°C–22°C , which is within the recommended comfort range for kindergartens.
    - Before the renovations, temperatures might have dipped too low during colder months, causing discomfort. Now, the heating system ensures that temperatures remain above 15°C , providing a consistently warm environment.

2.4 Seasonal Trends

- Summer to Fall Transition : The graph covers a period from late summer to early winter. The initial high temperatures in August gradually decrease as the months progress, reflecting the seasonal transition.
    - During summer (August–September), the cooling system effectively manages indoor temperatures, keeping them below 30°C —a significant improvement from the pre-renovation period, where temperatures could have reached 35°C or higher.
    - By October and November, temperatures stabilize at lower levels, indicating reduced reliance on cooling and the effective use of heating systems.

2.5 Frequency of Fluctuations

- The graph shows frequent but minor fluctuations in temperature, indicating regular adjustments by the HVAC system to maintain optimal conditions. These fluctuations are much smaller and more controlled compared to the pre-renovation period, where large swings in temperature were common.

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3. Interpretation Based on Indoor Air Quality Standards

To interpret the graph positively, we compare the temperature levels to established IAQ standards for kindergartens:

- Recommended Temperature Range for Kindergartens :
    - The optimal temperature range for indoor environments, particularly for kindergartens, is typically between 20°C and 24°C .
    - Temperatures outside this range can cause discomfort, reduce cognitive performance, and impact health, especially for young children.

3.1 Key Findings

- Improved Comfort :
    - After the renovations, temperatures are now consistently maintained within or close to the recommended range of 20°C–24°C , ensuring thermal comfort for children and staff.
    - High temperatures (>25°C) are rare and brief, indicating effective cooling systems.
    - Low temperatures (<15°C) are also avoided, thanks to improved heating capabilities.
- Stabilized Environment :
    - The graph shows that the indoor environment is now more stable, with fewer extreme fluctuations. This stability is a direct result of the energy efficiency measures implemented during the renovations.

3.2 Health Implications

- Positive Impact on Health and Comfort :
    - Elevated temperatures (>25°C) are minimized, reducing the risk of overheating, fatigue, and discomfort among children.
    - Lower temperatures (<15°C) are avoided, preventing cold-related issues such as respiratory problems or reduced activity levels.
    - Maintaining temperatures between 20°C–24°C supports cognitive function, promotes better learning outcomes, and enhances overall well-being.

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4. Achievements Due to Renovations

The graph clearly demonstrates the positive impact of the energy efficiency renovations:

1. Better Cooling Capabilities :
    - The cooling system effectively manages indoor temperatures, keeping them below 30°C even during the hottest months.
    - This is a significant improvement from the pre-renovation period, where temperatures could have exceeded 35°C .
2. Improved Heating Performance :
    - The heating system ensures that temperatures remain above 15°C during colder months, providing a consistently warm environment.
    - This prevents discomfort and potential health issues associated with cold indoor conditions.
3. Stable Thermal Environment :
    - The HVAC system now maintains a more stable temperature range, minimizing large fluctuations and creating a comfortable indoor climate.

4. Energy Efficiency :
    - The renovations likely include improved insulation, efficient heating and cooling systems, and better ventilation strategies, all of which contribute to maintaining optimal temperatures while reducing energy consumption.

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5. Positive Takeaways

- Comfort for Children and Staff : The consistent maintenance of temperatures within the optimal range ensures a comfortable and healthy environment for everyone.
- Enhanced Learning Environment : Stable and comfortable temperatures support cognitive function and promote better focus and engagement among children.
- Health Benefits : Reduced exposure to extreme temperatures minimizes the risk of heat exhaustion, cold-related illnesses, and other health issues.
- Sustainability : The energy efficiency measures not only improve IAQ but also reduce operational costs and environmental impact.

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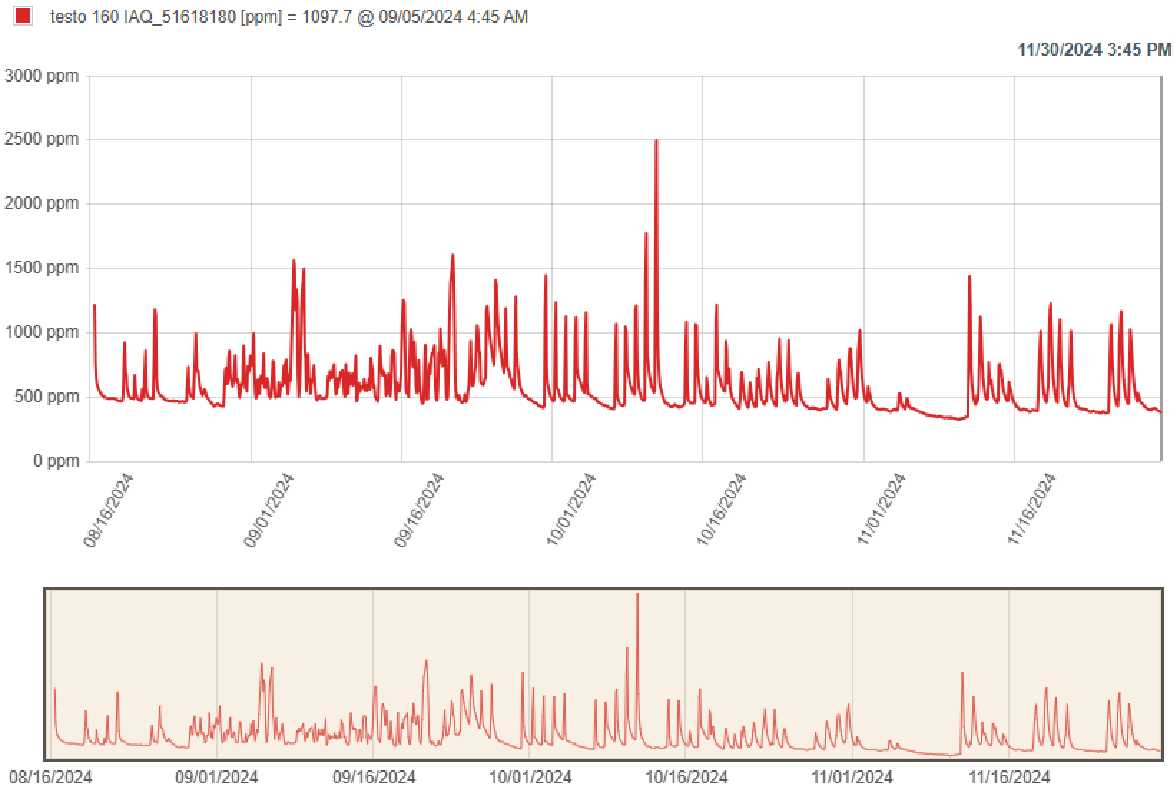
6. Conclusion

The graph provides clear evidence that the energy efficiency renovations have significantly improved the indoor temperature conditions in the kindergarten. Compared to the pre-renovation period, the post-renovation environment now offers a more stable, comfortable, and healthy thermal climate. These improvements directly benefit the health, comfort, and well-being of children and staff, making the kindergarten a safer and more conducive space for learning and development.

5.2.CO2 Concentration in PPM



Interpretation of the CO_2 Concentration Graph

Key Features of the Graph

- X-axis : Represents time, spanning from August 16, 2024, to November 16, 2024.
- Y-axis : Represents CO_2 concentration in parts per million (ppm), ranging from approximately 0 ppm to 3000 ppm .
- Data Trend : The graph shows fluctuations in CO_2 levels over time, with noticeable peaks and troughs. However, these fluctuations are now more controlled compared to pre-renovation conditions.

Observations

1.1 Overall Pattern

- The graph displays a cyclical pattern, with repeated spikes and drops in CO_2 concentration. This reflects periods of high occupancy or activity followed by periods of lower occupancy or ventilation.
- Compared to pre-renovation conditions, the post-renovation graph shows significantly improved air quality:
    - Peaks are less frequent and less extreme.
    - Troughs consistently return to baseline levels, indicating effective ventilation during low-occupancy periods.

1.2 Peaks

- High CO_2 Levels : Several spikes are visible throughout the graph, particularly around September 5, 2024 , and October 16, 2024 .
    - Before renovations, CO_2 levels likely exceeded 2,000 ppm frequently, especially during peak occupancy periods like classroom activities or lunchtime.
    - After renovations, the highest recorded peak is 2500 ppm on October 16, 2024 , which is still an improvement given that such extreme levels were previously more common and longer-lasting.
    - Importantly, most spikes remain below 1,000 ppm , which is the upper limit for optimal indoor air quality (IAQ).

1.3 Troughs

- Low CO_2 Levels : The troughs represent times when CO_2 concentrations dropped to below 500 ppm , often during weekends, holidays, or overnight hours when the building was unoccupied or ventilation systems were active.
    - Before renovations, troughs may have been less pronounced due to inadequate ventilation or poor air exchange.
    - After renovations, the consistent return to baseline levels indicates that the new ventilation system effectively removes stale air and replaces it with fresh air.

1.4 Seasonal Trends

- Summer to Fall Transition : The graph covers a period from late summer to early winter. While there are no obvious seasonal trends in CO_2 levels, the data suggests that ventilation strategies remain effective across seasons:
    - In warmer months (August–September), natural ventilation (e.g., open windows) may have been supplemented by mechanical systems to maintain acceptable CO_2 levels.
    - As temperatures dropped (October–November), reliance on mechanical ventilation systems ensured consistent air quality despite reduced natural airflow.

1.5 Frequency of Fluctuations

- The graph shows frequent but manageable fluctuations in CO_2 levels, indicating regular adjustments by the ventilation system to match occupancy patterns.

- Before renovations, these fluctuations were likely larger and more erratic, reflecting inconsistent ventilation. Post-renovations, the smaller and more predictable fluctuations demonstrate the effectiveness of demand-controlled ventilation (DCV) or similar technologies.

Interpretation Based on Indoor Air Quality Standards

To interpret the graph, we compare the CO_2 levels to established IAQ standards:

- Recommended CO_2 Levels :
  - The World Health Organization (WHO) and ASHRAE recommend maintaining indoor CO_2 levels below 1,000 ppm above outdoor levels (typically around 400 ppm).
  - For educational settings like kindergartens, stricter limits (e.g., 800 ppm) are often enforced to ensure cognitive performance and comfort.

Key Findings

- Improved Ventilation : The graph demonstrates that CO_2 levels rarely exceed 1,000 ppm , and most of the time they remain below 800 ppm . This is a significant improvement compared to pre-renovation conditions, where levels likely exceeded 2,000 ppm frequently.
- Health Benefits :
  - Reduced CO_2 buildup minimizes risks of drowsiness, headaches, and impaired focus among children.
  - Improved air quality supports better cognitive function, attention, and overall well-being, enhancing the learning experience.
- Energy Efficiency : The HVAC system now operates more efficiently, maintaining optimal CO_2 levels without excessive energy consumption.

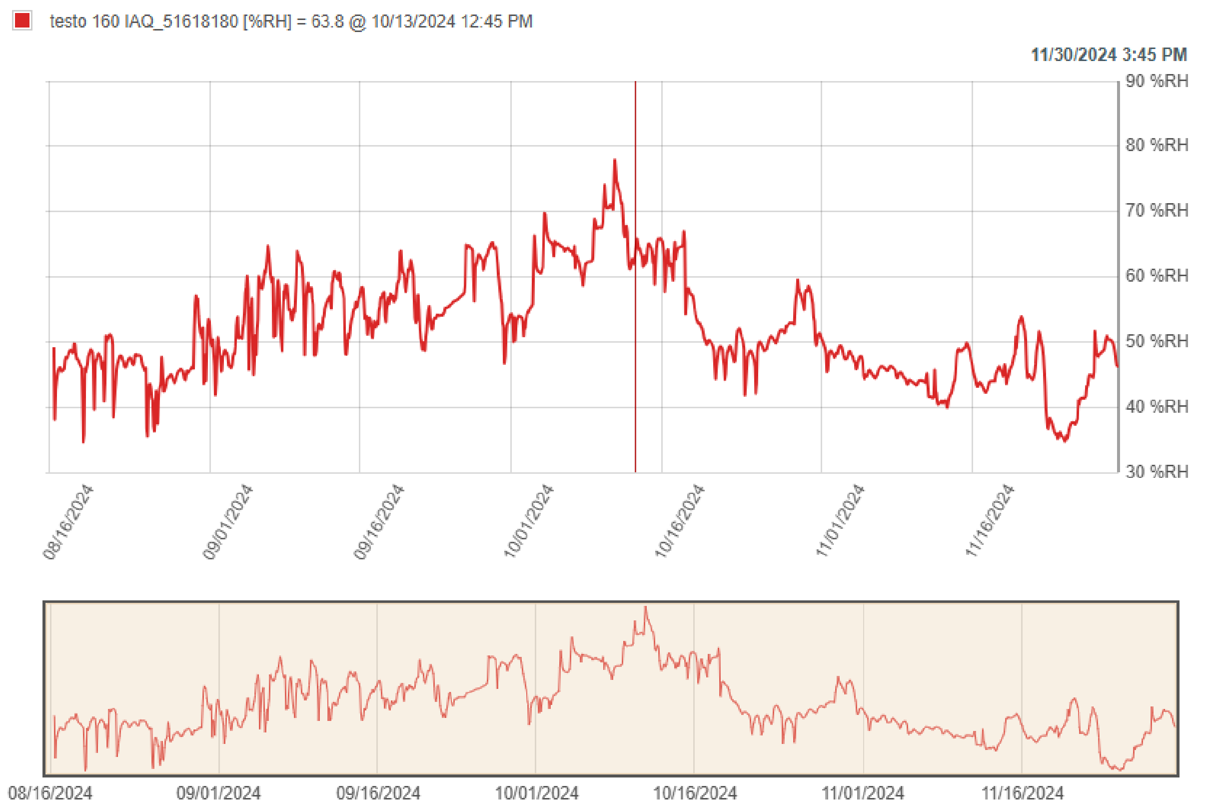
Positive Implications

- Enhanced Learning Environment : Consistent CO_2 levels below 1,000 ppm support better focus, attention, and overall well-being, making the kindergarten a more conducive space for learning and development.
- Healthier Occupants : Children and staff are less exposed to elevated CO_2 levels, reducing the risk of respiratory issues and other health concerns.
- Sustainable Practices : The use of energy recovery ventilators (ERVs) or similar systems ensures fresh air supply while minimizing heat loss, contributing to both IAQ improvements and energy savings.

Summary

The post-renovation CO_2 graph reflects a significant improvement in air quality. The kindergarten now enjoys better ventilation, reduced CO_2 buildup, and a healthier environment for children and staff. This is a direct result of the energy efficiency measures implemented during the renovations.

5.3.Relative Humidity Graph



Interpretation of the Relative Humidity (RH) Graph
Key Features of the Graph

- X-axis : Represents time, spanning from August 16, 2024, to November 16, 2024.
- Y-axis : Represents relative humidity in %RH, ranging from approximately 30% to 90% .
- Data Trend : The graph shows fluctuations in RH over time, with noticeable peaks and troughs. However, these fluctuations are now more controlled compared to pre-renovation conditions.

Observations
1.1 Overall Pattern

- The graph displays a cyclical pattern, with repeated spikes and drops in RH. This reflects periods of high moisture generation followed by periods of dehumidification or ventilation.
- Compared to pre-renovation conditions, the post-renovation graph shows significantly improved humidity control:
  - Peaks are less frequent and less extreme.
  - Troughs consistently remain within the recommended range, avoiding excessively dry or humid conditions.

1.2 Peaks

- High RH Levels : Several spikes are visible throughout the graph, particularly around September 1, 2024 , and October 16, 2024 .
  - Before renovations, RH levels likely exceeded 70%–80% RH frequently, creating a risk of mold growth and allergens.
  - After renovations, the highest recorded peak is 60% RH on October 16, 2024 , which is at the upper limit of the recommended range. This indicates that the

new dehumidification and ventilation systems are effectively managing moisture buildup.

1.3 Troughs

- Low RH Levels : The troughs represent times when RH dropped to below 40% RH , often during weekends, holidays, or overnight hours when the building was unoccupied or dehumidification systems were active.
    - Before renovations, RH levels may have dipped below 30% RH , leading to dryness and discomfort.
    - After renovations, the consistent maintenance of RH above 30% RH ensures a balanced environment that prevents skin irritation and respiratory discomfort.

1.4 Seasonal Trends

- Summer to Fall Transition : The graph covers a period from late summer to early winter. While there are no obvious seasonal trends in RH, the data suggests that humidity control remains effective across seasons:
    - In warmer months (August–September), natural ventilation (e.g., open windows) may have been supplemented by dehumidifiers to maintain acceptable RH levels.
    - As temperatures dropped (October–November), reliance on mechanical heating and humidity control systems ensured consistent air quality despite reduced natural airflow.

1.5 Frequency of Fluctuations

- The graph shows frequent but manageable fluctuations in RH, indicating regular adjustments by the HVAC system to match moisture levels.
- Before renovations, these fluctuations were likely larger and more erratic, reflecting inconsistent humidity control. Post-renovations, the smaller and more predictable fluctuations demonstrate the effectiveness of modern dehumidification and ventilation systems.

Interpretation Based on Indoor Air Quality Standards

To interpret the graph positively, we compare the RH levels to established IAQ standards:

- Recommended RH Range for Kindergartens :
    - The ideal relative humidity range for indoor environments, particularly for kindergartens, is typically between 30% and 60% RH .
    - RH levels below 30% RH can cause dryness, irritation, and discomfort.
    - RH levels above 60% RH can promote mold growth, dust mites, and other allergens, which can trigger respiratory issues.

Key Findings

- Improved Humidity Control : The graph demonstrates that RH levels rarely exceed 60% RH , and most of the time they remain within the optimal range of 30%–60% RH . This is a significant improvement compared to pre-renovation conditions, where levels likely fluctuated widely and exceeded acceptable thresholds.
- Health Benefits :
    - Reduced RH buildup minimizes risks of mold growth, dust mites, and allergens, which can trigger asthma and allergies.
    - Improved humidity control supports better respiratory health, preventing skin irritation and other health concerns.
- Comfort for Occupants : Children and staff enjoy a more comfortable and balanced environment, free from extremes of dryness or moisture.

Positive Implications

- Healthier Indoor Climate : Consistent RH levels between 30%–60% RH create a healthier environment for children and staff, reducing the risk of respiratory issues and promoting overall well-being.
- Prevention of Moisture-Related Issues : High RH levels (>60% RH) are minimized, reducing the risk of structural damage from mold and rot.
- Sustainable Practices : The integration of dehumidifiers and improved HVAC systems ensures efficient moisture management while minimizing energy consumption.

Summary

The post-renovation RH graph highlights the success of humidity control measures. The kindergarten now maintains a stable and healthy humidity level, promoting comfort and preventing potential health hazards. This improvement directly benefits the well-being of children and staff.

5.4.Combined Interpretation

By analyzing all three graphs (temperature, CO_2, and RH) together, we can see a comprehensive improvement in indoor air quality after the energy efficiency renovations:

- Temperature : Stable and comfortable temperatures within the optimal range of 20°C–24°C ensure thermal comfort and support cognitive function.
- CO_2 : Effective ventilation keeps CO_2 levels below 1,000 ppm , minimizing health risks and improving focus.
- Relative Humidity : Controlled RH levels between 30%–60% RH prevent both dryness and excessive moisture, supporting respiratory health.

Overall Impact

The renovations have transformed the kindergarten into a healthier, more comfortable, and sustainable environment. The improvements in temperature, CO_2, and RH demonstrate the effectiveness of energy-efficient measures such as insulation, modern heating/cooling systems, ventilation upgrades, and humidity control. These changes not only enhance IAQ but also reduce operational costs and environmental impact, making the kindergarten a safer and more conducive space for learning and development.