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# Demonstration of Energy Efficiency Measures in Four Kyiv School Buildings

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Prepared by
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Polish Foundation for Energy Efficiency
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# Summary

The Kyiv Institutional Buildings Energy Efficiency (KIBA) Project is being conducted to support the development of a program to improve the energy efficiency for heat and hot water provided by district heat in institutional (education, healthcare, and cultural) buildings owned and operated by State and Municipal Organizations in the City of Kyiv, Ukraine. KIBA is funded by the U.S. Department of Energy and is being conducted in cooperation with the World Bank and the Ukrainian State Committee for Energy Conservation.

A demonstration was conducted to verify the cost and performance of the major efficiency improvements, and to identify factors that need to be incorporated into the full-scale implementation of the program. The demonstration consisted of the installation of a heat meter, heat exchanger, control system, and weatherization measures in four school buildings that serve grades 1 through 11. School buildings of this type comprise 23% of the 1,678 institutional buildings selected for the KIBA program and represent 39% of the floorspace and 34% of the energy efficiency potential.

The average cost of \$30,771/building and \$3.67/m$^2$ was about 9% higher per square meter than for the cost estimated in the Technical Assessment. It is felt that the cost associated with full-scale implementation will be less due to competitive bidding, volume discounts, and installation efficiencies. Hence the actual costs are expected to be very near to those predicted in the Technical Assessment.

The predicted efficiency improvement of 22.8% is within the range of the improvement experienced in the demonstration (19.9 to 28.5%) and is about 10% lower than the average efficiency improvement experienced (25.3%).

The lessons learned from the demonstration effort that should be carried forward to the implementation phase include:

- Some weatherization measures are weather dependent and must be installed during periods of favorable weather conditions.
- Occupant education is required to prevent (or reduce) vandalism or other forms of occupant-related degradation of installed weatherization materials.
- Training of installation contractors is necessary to ensure high-quality installations.
- The length of time needed for the design process and approval points to a need to streamline this process and involve the district heating company.
- Cleaning of the secondary system within the building is a necessity.
- Heating system retrofits need to include air bleed valves in the risers and/or radiators.
- Follow-up service is needed to ensure correct operation of the heat exchanger system.
- A training program needs to be implemented to instruct facility/building managers on heat exchanger system operation.
- The district heating company must reconsider the sizing practices of the flow restricting orifices with regards to automatic control equipment.

# Acknowledgment

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# Introduction

The Kyiv Institutional Buildings Energy Efficiency (KIBA) Project is being conducted to support the development of a program to improve the energy efficiency in institutional buildings owned and operated by state and municipal organizations in the City of Kyiv, Ukraine. KIBA is funded by the U.S. Department of Energy and is being conducted in cooperation with the World Bank and the Ukrainian State Committee for Energy Conservation.

Two assessments were completed for the KIBA Project in August 1997:

> *Kyiv Institutional Buildings Sector Energy Efficiency Program: Technical Assessment*, PNNL-11644, Pacific Northwest National Laboratory, Richland, Washington.
> *Kyiv Institutional Buildings Sector Energy Efficiency Program: Lending and Implementation Assessment*, PNNL-11653, Pacific Northwest National Laboratory, Richland, Washington.

The purpose of the Technical Assessment was to identify the cost-effective energy efficiency potential, and the Lending and Implementation Assessment provided a number of financial and institutional options for implementing the project. The assessments have identified a potential $38 million investment to install heat exchangers, heating system controls, weatherization materials, and other measures in 1,678 healthcare, education, and cultural buildings supplied by district heat. The measures identified are predicted to reduce energy consumption by an average of 26%.

A demonstration in kindergartens and schools up to the twelfth grade was coupled with the assessment as these building types account for nearly 60% of the buildings and floor-space targeted under the program. The purposes of the demonstration program are to:

- Verify the technical and cost performance of the main measures selected (heat exchangers, heating system controls, and weatherization measures).

- Identify major obstacles and lessons that may impact program implementation in order to subsequently incorporate these into the planning and program implementation processes.

- Generate awareness and visibility for a potential energy efficiency program.

This report provides a review of the technical performance of the measures and identifies the lessons learned. Awareness and visibility are being provided by the International Centre of Energy Efficient Technologies within the State Committee of Ukraine for Energy Conservation.

Chapter 2 provides the measures installed, a description of the four participating schools, and the steps and experiences in the installation process. Chapter 3 presents the efficiency improvement experienced resulting from the installation of the measures and other lessons such as operation, maintenance, and

occupant response. The predicted cost and efficiency improvement from the Technical Assessment are compared with the installed cost and actual performance of the measures in Chapters 2 and 3. The results are summarized in Chapter 4 to identify the implications and recommendations for program implementation.

# Configuration and Installation

This chapter provides a description of the four school buildings, a description of the measures installed, and the installation experiences to include the predicted and actual installed cost of the measures.

## School Building Description

This section provides a brief description of each of the four schools that participated in the demonstration. Table 1 below summarizes the main parameters of each school.

**Table 1**. Description of Schools

| School number | 272 | 303 | 159 | 324 |
|---|---|---|---|---|
| Address | Lunacharsky St. 5D | Dragomanov St. 9A | Gen. Tupikov St. 22 | Gen. Tupikov St. 22/23 |
| Number of floors | 3 | 3 | 4 | 4 |
| Floor space [m2] | 8,921 | 10,301 | 9,511 | 5,026 |
| Year built | 1988 | 1992 | 1975 | 1995 |
| Grades | 1-11 | 1-11 | 5-11 | 1-3 |
| Number of students | 1050 | 2400 | 970 | 550 |
| Number of classrooms | 65 | 44 | 45 | 24 |
| Number of offices | 7 | 6 | 5 | 6 |
| Dining hall | 1 | 1 | 0 | 0 |
| Sport hall | 2 | 2 | 1 | 1 |
| Conference room | 1 | 1 | 1 | 0 |

### School 272 Other Features/Comments

This building houses Ukraine College, a progressive internationally oriented school with many experimental programs, such as early major selection, and a children's international diplomacy club.

- The left wing of the school is served by the heat exchanger substation that was installed and the right wing is heated by an existing hydroelevator substation.

### School 303 Other Features/Comments

This school operates in two shifts (morning/afternoon) to accommodate the high number of students separated into 81 classes.

- School number 303 has a large detached swimming pool facility. The space and water heating for the pool area were not included in the project as the heat is provided by an independent substation that it is operated and billed separately.

**School 159 Other Features/Comments**

- Schools 159 and 324 are adjacent to each other (share a common wall), and the substation located in the basement of building 324 houses the heat exchanger systems that serve both buildings.

- Both schools 159 and 324 received the heat exchanger retrofit, but number 159 did not receive the weatherization measure.
- This school was reported to be generally underheated prior to the retrofit.

- This school specializes in teaching English and French languages.

**School 324 Other Features/Comments**

- Schools 324 and 159 are adjacent to each other (share a common wall), and the substation located in the basement of building 324 houses the heat exchanger systems that serve both buildings.

- This school specializes in teaching the English language.

- Both schools 324 and 159 received the heat exchanger retrofit, but number 159 did not receive the weatherization measure.

- This school was reported to be generally overheated prior to the retrofit.

## Measures

Two classes of measures were installed in the four schools as follows:

- **Weatherization** measures to reduce infiltration and improve occupant comfort. The weatherization measures include weather-stripping around the windows and doors and external caulking to seal joints.

- **Heat supply system** measures to improve control of the indoor temperature with respect to outdoor conditions and the feedback from the indoor sensors. This system controls the delivered heat to the space which prevents overheating and reduces the heat energy supplied during unoccupied periods. The heat supply system measures involve retrofit of the heat substation to include heat exchangers, circulation pumps, cut-off valves, filters, and control system to regulate indoor temperatures and set-back the indoor temperature during unoccupied periods.

- In addition, **heat meters** are included in each installation to verify the performance of the weatherization and control measures in reducing heat energy consumption.

In order to eliminate severe cold air drafts and increase the temperature in underheated spaces during the winter, building occupants attempt to weatherize all of the windows. Typical “weatherization” currently

used consists of newspaper inserted into the frames or tape applied over the gap between the operable portion of the window and the frame. Either approach virtually eliminates the opening of windows, which prevents the entry of fresh air during periods of overheating and/or when the occupied space becomes stuffy. Doorways were not weatherized and cracks were not sealed.

The weatherization measures installed on the windows permitted the windows to be opened normally and reduced the infiltration when the windows are closed. Weatherization materials selected were polyethylene "V"-seal installed in the gaps between the frame and window wing, and "P"-seal (Santa Foam) installed on the outside. A P-type seal was applied to the door frame to reduce infiltration when doors were closed. Caulking was applied to seal the joint between the window frame and wall.

Presently, all the school buildings in Kyiv are connected to the district heating system. Hot water from the district heating system is introduced directly to the building heating system and radiators. Theoretically, the supply water temperature can be increased during the winter extremes to as high as 150 C and the temperature must be reduced (for space heat control and for safety reasons) by mixing the supply water with the return water. Practically, the temperature of the water supplied by the district heating company rarely reaches 85 to 90 C during the coldest periods. Mixing is done by hydroelevators which are, in principle, a Venturi nozzle. In the working section of the nozzle, increased dynamic pressure reduces the static pressure, which generates "suction" in the pipe connected to the return pipe and thus accomplishes recirculating and mixing without the use of recirculating pumps. This system is simple and does not require electrical energy to operate. However, its strong dependency on system pressures and complete inability to be regulated cause inefficient use of energy, underheating during the cold days, and overheating during the mild days.

The supply water flow is restricted by a fixed diameter orifice installed upstream of the hydroelevator. The orifice sizing and its installation is performed by the district heating company and the installation is sealed to prevent tampering. It is important to note that the orifices are sized for the design supply temperature, which is much higher than the water temperature actually delivered. For this reason, many buildings are underheated.

An important disadvantage of the old hydroelevator system is the direct introduction of the district heating water to the building. This permits limestone and debris to be deposited in the pipes and the radiators, which results in a decrease in the performance of the heating system and malfunctioning of radiator valves. A heating system plugged with limestone and debris has lower heating capacity through lower surface temperature of the heating elements and thus underheating of the space. The district water in Kyiv's system is extremely dirty, contaminated with solids such as rust and soil particles. Probably due to large losses, the required quantity of feed water is not treated properly and has a large content of minerals which deposit on the colder surfaces of the building heating system (pipes and radiators). Systems with direct circulation of district heating water cannot be easily cleaned, cannot be kept clean, and their life is severely reduced. Another significant problem with a direct connection is frequent leaks in pipes and radiators due to pressure fluctuations.

The heat supply system control measures consisted of replacing the hydroelevators with a heat exchanger-based heat supply system, usually referred to as a "substation." This system effectively isolates the building heating loop from the district heating system and provides for accurate control of the heat input to the building with respect to the ambient condition, indoor temperature, and the building occupancy schedule. The primary side of the heat exchanger is connected to the district heating system and the heating water is supplied at a temperature set by the district heating company according to a graphic, as a function of the ambient temperature. The actual heat input required by the building is controlled by the control system which drives a direct-acting modulating valve on the primary side of the heat exchanger. This valve controls the heat input by controlling the flow of the heating water. The secondary side of the heat exchanger is connected to the building heating loop and water is circulated by the circulating pump at a constant flow. Filters were installed on the primary circuit of the heat exchangers to prevent or reduce fouling of the heat exchanger surface.

The system control sequence is driven by the indoor temperature measured in a representative space in the building (one of the classrooms), by the ambient temperature and by the time-of-the-day input representing the building occupancy schedule. If sufficient heat supply is provided by the district heating system, the control system maintains a preset indoor temperature during the occupied mode and lowers the set point for an unoccupied mode (nights, weekends), thus conserving energy.

Heat meters also were installed on the primary circuit to measure the amount of heat actually consumed. An important note is that only space heat consumption was metered–hot water was not. In order for a customer to be billed for actual heat supplied by the district heating company, both heat and hot water consumption have to be metered together. As a result, the billing for the four schools continues to be based on estimated, not actual, heat consumption. The choice to measure only the space heat was made as the heat exchanger and control system were only for space heating purposes, and it was desired to obtain more precise estimates of the heating system efficiency improvements (an estimated 80% of total heat supplied to educational buildings is used for space heating purposes).

Weatherization and heating system measures were installed in buildings of schools 272, 303, and 324. School 159 received retrofit of the substation; the windows were not weatherized.

## Installation Experience

The installation of the measures progressed in two phases. The weatherization measures were installed in the spring of 1997, and the heat control systems were installed in the fall of 1997. This section provides a discussion of the experience and considerations for implementation of the two types of measures.

### Weatherization Measures

#### Installation

The installation of the weatherization measures took place during the spring of 1997 and was completed in early December 1997. It was overseen by the Polish Foundation for Energy Efficiency (FEWE) in cooperation with the Ukraine Agency for Rational Energy Use and Ecology (ARENA-ECO). The

weatherization materials were purchased by PNNL according to specifications provided by FEWE. Ukrainian technicians trained by FEWE staff performed the installation of the weatherization measures.

A substantial portion of the building heat losses are caused by infiltration through the windows. Every window and door is constructed with a gap between the window wing and the frame for proper operation. Depending on the quality and condition of the windows, this gap is anywhere between 0 to 5 millimeters. Over time, window frames may become distorted, hinges may get loose, and latches may not work properly. Multiple layers of paint on the window frames also cause a change in the gap size and, in many instances, difficulties with closing the windows.

In order for the window and the door seals to be effective, and in order to ensure the desired long life, the installation process must include the following:

- The windows must be inspected and, if required, the wing and frame must be re-fitted to ensure an even gap around the wing. A small gap will cause the seal to be damaged or "stripped" when the window closes. Occasionally, rotten and/or damaged parts of the window may have to be replaced. The final size of the gap must be considered for the seal (size and type) selection.

- The old window paint (especially on wood frame windows) must be stripped, the wood must be treated, and new paint must be applied. This must be done at least to the surfaces that will hold (will be covered with) the seals and to the surfaces which will come into contact with the seal. The main reason for this is to ensure a good base for the adhesive and to protect the seal material and the window frame material.

- Prior to application of the seals with adhesive, the surfaces must be well prepared, dry, and clean.

- The seals must be continuous, installed on the same "level." For example, the V-seal must be installed on the perimeter of the wing on the external side only. Installation of part of the seal on the outside and part of the seal on the inside creates an unsealed gap and causes seals to work improperly.

- Proper attention must be given to the selection and location of the seals. Compression seals (foam profiles, soft "O" rubber shapes) are designed to be squeezed between "butting" surfaces and should be so installed. The V-seal is designed for surfaces that will maintain the gap size (when closing, these surfaces will move along each other like a shear). Using seals on improper places reduces their performance and life.

- The seal size (such as the height of the compression foam seal) must be selected carefully. Excessive compression will damage the seal and will cause problems with window closing.

The combination of a V-seal and outdoor P-seal was installed on all windows in school 272, and on about 3% of the windows in school 324. The P-seal was installed on three sides (left, right, and top) on only lower, larger window wings (most of the windows have four wings). The upper, smaller wings did not have seals installed. A V-seal was installed on the internal surface of the bottom side of the fixed frame.

In the location of this V-seal, a compression seal would be more appropriate. This arrangement was likely selected due to the rain water drainage issue, which may compromise the performance of the seal. The majority of the seals functioned properly.

A compression type, silicone rubber P-seal was installed on all windows in school 303, and on approximately 70% of the windows in school 324. Due to a combination of poorly prepared surfaces, vandalism, and that the seal was installed on the shearing surfaces (perpendicular to the window pane), the seal was damaged during the first few openings and closings.

A V-seal was installed on about 27% of the windows in school 324. The seal was installed on "butting" surfaces where the compression seal would be more appropriate. V-seals on some of the windows were also damaged or missing and do not seal properly due to the uneven, rough, unprepared surfaces on both sides of the seal (the bearing surface and the surface on the opposite side). Some damage was also due to vandalism.

Implementation plans for future projects must include improved training of the installation foreman and crew members, ongoing quality management and control, and strict acceptance of the work performed by well-trained personnel.

#### Considerations

- The installation of some weatherization measures is weather dependent. The installation of all weatherization materials must take place in favorable weather conditions or the installation of weatherization materials must be phased to install those that are weather dependent under favorable weather conditions. Note that phasing the installation may result in higher costs for crews to revisit buildings to complete installations and/or cause disruption for the occupants.

- Occupant education is required to prevent (or reduce) vandalism or other forms of occupant-related degradation.

- Training is necessary to ensure acceptable quality of installations.

- It has been noted that parents provide both labor and monetary support to school maintenance. Perhaps materials and training for installation of weatherization materials could be provided to parents. This may have spill-over benefits to residential markets.

### Control Measures

#### Installation

The installation of the heating system control measures was specified by FEWE and contracted to Honeywell Ukraine by PNNL. Honeywell contracted to the firm Kyiv Zonal Research and Project

Institute for Civil Construction (ZNIIEP) to perform the design and generate the necessary technical documentation and drawings for installation and approval process. The actual installation work was done during November 1997 by the local contractor selected and contracted by Honeywell Ukraine.

The heating capacity available to each building connected to the district heating system is currently effectively controlled by the supply water temperature. The district heating company is using graphics (predetermined control logic based on ambient temperature) to modulate the supply water temperature based on outdoor temperature. The supply water temperature is in general below the required level and many buildings are underheated at lower ambient temperatures. Additionally, the flow to the buildings is controlled by a flow restricting orifice. Such an orifice is required by the district heating company for buildings without temperature controls. For the buildings with heat supply modulating equipment such as the four demonstration buildings, the flow restricting orifice is technically not necessary, but is still required by current "norms." The orifices, sized and installed by the district heating company are designed with assumption of "design conditions" (150 C hot water supply with an outdoor temperature of -22 C). In reality, the district heating company provides hot water of no more that 85 to 90 C at an outdoor temperature of -22 C. This obviously results in insufficient heat supply.

The district heating company has, at the time of installation of the substation, installed new orifices in each of the four demonstration sites. The orifices limit the supply water flow to unacceptable levels and the heat input to the schools was insufficient to heat the buildings to design levels. The orifices combined with lower-than-required supply water temperature caused the four demonstration buildings to be somewhat underheated. In three of the four demonstration sites, the orifice was "temporarily" removed and the buildings were close to the 18 C interior design temperature with the control valve in the fully open position. The orifice removal issue must be addressed on a legislative/management level and agreement must be reached with the district heating company, either to remove the orifices completely, or to install orifices with a sufficiently large opening. Technically, the Honeywell control system effectively eliminates the need to install the flow limiting orifices since the system controls the heat input much more accurately and according to real heat demand, as opposed to a static, fixed control provided by the orifice.

The systems in all four sites were installed according to the design and in an organized and professional manner, with some small errors and shortcomings which are described in the following text for each school. The equipment in all four schools complies with accepted industrial standards.

All schools have a four-pipe heating system input - two pipes for space heating (supply and return) and two pipes for domestic water heating (supply and recirculation). Within each building the heating system is a one-pipe configuration meaning that the radiators are in series. Substations were installed only for the space heating. A provision for future installation of a heat exchanger for domestic hot water was made in each system.

The school personnel unrealistically expected that the installation of the heat exchanger substation would increase the indoor temperature. In fact, school number 272 experienced higher indoor temperatures, but this is likely due to removal of the orifice. In reality, with insufficient heat supplied by the district heating company, the heat exchanger-based substation will not provide more heat to the building. Improved comfort may only be attained by the weatherization, as it reduces heat losses and cold air draft.

Many of the building heating system problems were not addressed by this demonstration project. The installation of a sophisticated substation must take into consideration the existing building heating system which is supplied by heat from the substation. The school buildings are about ten years old and the internal heating system (radiators, pipes, valves) are quite deteriorated. In order to ensure proper operation of the heating system, the pipes and radiators must be chemically cleaned, faulty parts replaced, and missing components, such as air bleeding valves, must be installed. Installation of air bleeding valves in each radiator or at least in each riser is necessary. Currently, many of the radiators are clogged with air and do not function properly, thus adding to the underheating problem. Also, the internal heating system capacity was designed for the standard supply water temperatures, and for the current supply condition, the number and sizes of radiators is not sufficient.

The substation requires periodic maintenance and the attention of professional service personnel in case of emergency. The district heating water is quite dirty and the strainers got plugged up in less than two weeks. Schools often do not have qualified maintenance personnel and the installer's contract does not provide for servicing beyond the manufacturer's warranty. Currently, the schools have minimal support for the maintenance and possible emergencies.

Following is the description of installations in each demonstration site.

**School 272 -** The design capacity of the heating system is 813 kW. The installed heat exchanger capacity with 150 C primary input and a flow of 13.95 $m^3$/hr is up to 1300 kW. The primary side conditions were 10.8 $m^3$/hr, 61/47 C (supply/return), and the secondary (building) side conditions were 13.6 $m^3$/hr, 51/39 C. All components installed are sufficient for the maximum capacity of the heat exchanger and according to industry standards. The flow-limiting orifice installed by the heating company has been removed and under ambient conditions of +3 to 6 C, the system operates as expected, with no underheating reported. The inspection revealed a few minor problems as follows:

1. The return pipe from the building (secondary side) is not equipped with a strainer to protect the circulating pumps and the heat exchanger surface on the secondary side. Plate heat exchangers used for this application are known to be sensitive to fouling by solid particles such as rust, limestone, and other debris usually found in the building piping system. Installation of a strainer is strongly recommended. Clogging of the heat exchanger surface will likely occur in less than one year without a strainer and the cost of such maintenance would definitely exceed the cost of the strainer.

2. Part of the building (approximately 20% of the floor space) was not connected to the secondary side of the heat exchanger and is still using the hydroelevators (2 pcs.). It was explained that the main reason for such an arrangement was difficulty with reworking the plumbing. Although it would be highly recommended to rectify this installation in the future, it was a convenient arrangement for verification of system performance. The heat meter is installed upstream of both systems and measures the total consumption. The heat exchanger capacity is sufficient for the entire building.

3. The heating system has only a limited means of air purge and some radiators are not functioning because of air trapped in the loop. It is necessary to install an automatic air purger and/or air purging valves at the top floor radiators.

4. The substation system has multiple expansion tanks designed for a maximum operating pressure of 0.25 MPa. Currently, the expansion tanks and pressure relief safety valves are closed and the pressure regulating feed valve is bypassed. Thus, the pressure in the secondary side is much higher than required and the system is open for expansion to the return side of the primary loop. The reason for this is an attempt to extract air from the secondary side loop because the heating system does not provide for air purging. Before commissioning, the system pressure must be set to the proper range and feed water must be controlled by the pressure regulating valve.

**School 303 -** The design capacity of the heating system is 604 kW. The installed heat exchanger capacity with assumed 150 C primary input temperature and the flow of 12.90 $m^3$/hr is up to 1200 kW. The primary side conditions were 5.41 $m^3$/hr, 59/35 C, and the secondary (building) side conditions were 15.23 $m^3$/hr, 41/34 C. All components installed are sufficient for the maximum capacity of the heat exchanger and are sized according to industry standards. The flow-limiting orifice installed by the heating company is in place, and even under ambient conditions of +3 to 6 C the system capacity is insufficient and school building is underheated with an average indoor temperature of around 16 C. Minor problems, which must be addressed prior to acceptance of the installation follow:

1. The thermostat is located about 30 cm below the ceiling in a workshop. It is recommended that the thermostat be moved to a more representative room and installed at 1.5 to 1.6 meters above the floor. The present location of thermostat was requested by school personnel to prevent damage to it. If the thermostat remains in its existing location, a higher setting is recommended.

2. Based on the difference between the total reading of water flow meters located on the primary side inlet and outlet pipes and based on observed pressure loss in the secondary side, it was believed that a substantial water leak (up to 10 $m^3$/day) existed somewhere in the building or that the heating water is used as tap water. An extensive inspection of the building heating system, hot water piping, and a flow measurement in the feed pipe found that the system leak is 21.1 liters/hour -- substantially less than was initially believed. This problem is not related to the installation of the substation performed by Honeywell and must be addressed by the school. It is important to note that the measurement of flow under the given conditions is very difficult and may be inaccurate. The actual leak may be much less, but is not believed to be greater.

3. The pressure gauge installed by the district heating company is faulty and needs to be replaced. Since it is located upstream of the main shutoff valve, this must be done by the district heating company. The pressure gauge located on the suction side of the lower circulating pump is also not functioning and should be replaced by Honeywell.

4. The flow restricting orifice is still installed in this school and there is insufficient heating capacity for the school buildings space heating needs. The issue of removing the restricting orifice must be resolved with the district heating company and/or by legislative order.

5. It is very difficult to purge air from the heating system. Air vents installed in upper floor radiators and/or an automatic air purger must be installed. Air vents should be in the original system and are not part of the substation installation.

6. The proper operating pressure in the secondary system must be set, the feed valve must be adjusted, and the expansion tanks and pressure relief valves must be engaged. According to Honeywell, this work is in progress.

7. It was observed that the readings of the flow meter in the primary supply side (part of the heat meter) and the flow meter installed in the primary return side are different. The difference is approximately 180 liters/hour. This may be caused either by a faulty flow meter in the supply side (a faulty meter usually shows less flow) or by (if adjustable) incorrect pulse-to-volume ratio of the heat meter readout. Honeywell was asked to rectify this issue.

8. The return pipe from the building (secondary side) is not equipped with a strainer to protect the circulating pumps and the heat exchanger surface on the secondary side. Plate heat exchangers used for this application are known to be sensitive to fouling by solid particles such as rust, limestone, and other debris usually found in the building piping system. Installation of a strainer is strongly recommended as clogging of the heat exchanger surface will likely occur in less than one year without a strainer and the cost of such maintenance would definitely exceed the cost of the strainer.

**School 324 -** The design capacity of the heating system is 354 kW. The installed heat exchanger capacity with assumed 150 C primary input temperature and flow of 7.525 $m^3$/hr is up to 700 kW. The primary side conditions were 7.3 $m^3$/hr, 63/38 C, and the secondary (building) side conditions were 20.8 $m^3$/hr, 47/38 C. All components installed are sufficient for the maximum capacity of the heat exchanger and are sized according to industry standards. The flow-limiting orifice was temporarily removed with the permission of the district heating company and reinstalled in February 1998. With the flow restrictor removed and ambient conditions +3 to 6 C, the system capacity is sufficient and the school building is heated to normal conditions of 18 to 19 C in classrooms and around 17 C in hallways. When the flow restrictor was replaced, the interior spaces were underheated. Minor problems which must be addressed are the following:

1. The flow meter in the primary return pipe was not functioning -- this needs repair or replacement.

2. The thermostats for both schools (154 and 324) were initially installed in the same room about 30 cm below the ceiling. This room is small, relatively warm, and does not represent the general space condition. It was recommended that the thermostats be relocated and this was done.

3. The operating pressure of the secondary circuit is governed by the design of the expansion tanks which were designed for a maximum pressure of 0.25 MPa and a normal operating pressure of 0.15 MPa. The current operating pressure in the secondary circuit is about 0.54 MPa and the line to the expansion tanks is closed. This is a safety issue and must be resolved.

4. The return pipe from the building (secondary side) is not equipped with a strainer to protect the circulating pumps and the heat exchanger surface on the secondary side. Plate heat exchangers used for this application are known to be sensitive to fouling by solid particles such as rust, limestone, and

other debris usually found in the building piping system. Installation of a strainer is strongly recommended as clogging of the heat exchanger surface will likely occur in less than one year without a strainer and the cost of such maintenance would definitely exceed the cost of the strainer.

**School 159 -** The design capacity of the heating system is 536 kW. The installed heat exchanger capacity with assumed 150 C primary input temperature and flow of 10.7 $m^3$/hr is up to 1000 kW. The primary side conditions were 11.2 $m^3$/hr, 58/40 C, and the secondary (building) side conditions were 18.8 $m^3$/hr, 42/31 C. All components installed are sufficient for the maximum capacity of the heat exchanger and are sized according to industry standards. The flow restricting orifice was temporarily removed with the permission of the district heating company and reinstalled in February 1998. With the flow restrictor removed and ambient conditions +3 to 6 C, the system capacity is sufficient and the school building is heated to normal conditions of around 18 to 20 C in classrooms and around 16 C in hallways. When the flow restrictor was replaced, the interior spaces were underheated. One minor problem which must be addressed follows:

1. The return pipe from the building (secondary side) is not equipped with a strainer to protect the circulating pumps and the heat exchanger surface on the secondary side. Plate heat exchangers used for this application are known to be sensitive to fouling by solid particles such as rust, limestone, and other debris usually found in the building piping system. Installation of a strainer is strongly recommended as clogging of the heat exchanger surface will likely occur in less than one year without a strainer and the cost of such maintenance would definitely exceed the cost of the strainer.

**School 284 -** This school was not part of the demonstration project and is still equipped with a hydroelevator substation. This school was selected for monitoring purposes and for establishing the baseline heat consumption. The school building is virtually the same as school number 272. Supply water conditions were 61/55 C, and water temperature after the hydroelevator were 54/49, which is very similar to other sites. The flow restricting orifice was removed and indoor temperatures were 17.9 to 18.7 C in the classroom with up to 36 children per class, and 15.7 to 17.4 C in hallways. School management complained about very cold indoor temperatures during the cold winter days. The indoor conditions in this school were colder than in any of the demonstration schools.

**Considerations**

- The length of time for the design process and approval points to a need to streamline this aspect of the installation. Streamlining the process would also lower the cost of the design and permitting process.

- As part of the retrofit, cleaning the secondary system within the building is a necessity.

- Heating system retrofits need to include valves in the risers and/or radiators to bleed air from the system.

- Follow-up service is needed to ensure correct operation of the system.

- A training program needs to be implemented to instruct facility/building managers on system operation.

- The district heating company required that a flow meter and a strainer be installed in the return line on the primary side of the heat exchanger in addition to a flow meter and strainer on the supply side of the heat exchanger primary line. The additional flow meter increases the cost about 2 to 4% and the additional strainer adds about 1%, for a total increase of 3 to 5%. The requirement raises two issues for discussion with the district heating company:

  - In the existing configuration using a hydroelevator, no flow meters are required and the customer is billed for estimated consumption. The explanation for the additional flow meter is to identify losses that may be associated with make-up water drawn from the district system for leakage occurring within the building or for unauthorized taps on the line. This raises the question about whether the customer should bear the cost for this extra meter.

  - The district heating company requires that flow restricting orifices be installed in each building. It is important to realize that the orifices are sized based on nominal design parameters of the supply heating water and that the actual parameters are substantially lower. This results in insufficient heat supply to the building.

## Installation Costs

The predicted and actual costs of the installed measures by school for materials and labor are shown in Table 2. The predicted cost is drawn from the technical assessment and adjusted to the space of each school.

The estimated and actual costs of installation (material and labor) are in a range of -7.5% to 38.9%. The main reason for the variation is the prototype nature of the demonstration work, which usually yields higher labor cost, absence of quantity discounts, and learning time/cost. The most evident difference is in installation labor for the heat meters, which would certainly be reduced for the large volume of installations. Also, the cost estimates provided by the KIBA technical report are tied to floor space and thus individual buildings smaller than average will yield higher actual cost and vice versa. On average, the cost variation between the estimated and actual costs is 9.2%, which is quite reasonable. It is estimated that the cost reduction for higher volume installations (100 buildings and more) will be approximately 10% due to material cost discounts and more effective labor costs.

**Table 2**. Estimated and Actual Cost of Measures by School

| **ESTIMATED COST** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number | Heat Meters | | | Heat Control Systems | | | Weatherization | | | Retrofit Total | | | |
| | Material | Labor | Total | Material | Labor | Total | Material | Labor | Total | Material | Labor | Total | Per $M^2$ |
| 272 | 3,404 | 194 | 3,598 | 15,871 | 4,012 | 19,883 | 3,059 | 3,602 | 6,661 | 22,333 | 7,809 | 30,142 | 3.38 |
| 303 | 3,930 | 224 | 4,154 | 18,587 | 4,699 | 23,286 | 3,532 | 4,159 | 7,691 | 26,048 | 9,083 | 35,131 | 3.41 |
| 324 | 1,918 | 109 | 2,027 | 10,161 | 2,569 | 12,730 | 1,723 | 2,029 | 3,752 | 13,802 | 4,707 | 18,509 | 3.68 |
| 159 | 3,629 | 207 | 3,836 | 15,022 | 3,798 | 18,820 | N/A | N/A | N/A | 18,651 | 4,005 | 22,656 | 2.38 |
| Average | 3,220 | 184 | 3,404 | 14,910 | 3,770 | 18,680 | 2,771 | 3,264 | 6,035 | 20,208 | 6,401 | 28,118 | 3.36 |
| | | | | | | | | | | | | | |
| **ACTUAL COST** | | | | | | | | | | | | | |
| Number | Heat Meters | | | Heat Control Systems | | | Weatherization | | | Retrofit Total | | | |
| | Material | Labor | Total | Material | Labor | Total | Material | Labor | Total | Material | Labor | Total | Per $M^2$ |
| 272 | 2,730 | 1,062 | 3,792 | 17,456 | 6,788 | 24,244 | 3,414 | 3,323 | 6,738 | 23,600 | 11,173 | 34,774 | 3.90 |
| 303 | 2,730 | 1,099 | 3,829 | 16,884 | 6,799 | 23,683 | 1,038 | 3,932 | 4,970 | 20,652 | 11,830 | 32,482 | 3.15 |
| 324 | 2,145 | 1,090 | 3,235 | 12,220 | 6,208 | 18,428 | 1,680 | 2,366 | 4,046 | 16,045 | 9,664 | 25,709 | 5.12 |
| 159 | 2,464 | 1,111 | 3,575 | 14,676 | 6,616 | 21,292 | N/A | N/A | N/I | 17,140 | 7,727 | 24,867 | 2.61 |
| Average | 2,517 | 1,091 | 3,608 | 15,309 | 6,603 | 21,912 | 2,044 | 3,207 | 5,251 | 19,359 | 10,099 | 30,771 | 3.67 |
| | | | | | | | | | | | | | |
| **PERCENT DIFFERENCE -- ACTUAL TO ESTIMATED** | | | | | | | | | | | | | |
| Number | Heat Meters | | | Heat Control Systems | | | Weatherization | | | Retrofit Total | | | |
| | Material | Labor | Total | Material | Labor | Total | Material | Labor | Total | Material | Labor | Total | Per $M^2$ |
| 272 | -19.8% | 446.6% | 5.4% | 10.0% | 69.2% | 21.9% | 11.6% | -7.7% | 1.2% | 5.7% | 43.1% | 15.4% | 15.4% |
| 303 | -30.5% | 389.9% | -7.8% | -9.2% | 44.7% | 1.7% | -70.6% | -5.5% | -35.4% | -20.7% | 30.3% | -7.5% | -7.5% |
| 324 | 11.9% | 895.8% | 59.6% | 20.3% | 141.7% | 44.8% | -2.5% | 16.6% | 7.8% | 16.3% | 105.3% | 38.9% | 38.9% |
| 159 | -32.1% | 436.3% | -6.8% | -2.3% | 74.2% | 13.1% | N/A | N/A | N/A | -8.1% | 92.9% | 9.8% | 9.8% |
| Average | -21.8% | 493.3% | 6.0% | 2.7% | 75.2% | 17.3% | -26.2% | -1.7% | -13.0% | -4.2% | 57.8% | 9.4% | 9.2% |
| Note: Actual costs of material and labor provided by FEWE | | | | | | | | | | | | | |

# Performance

This chapter presents the efficiency improvement experienced resulting from the installation of the measures and other lessons such as operation, maintenance, and occupant response.

## Efficiency Improvement

### Baseline

Baseline energy consumption, the basis for energy saving evaluation, is typically established by metering the building during the heating season preceding the implementation. This was not possible due to the time constraints, and an alternative method was used to determine the baseline. A combination of computer modeling calibrated for the post-installation heat consumption and comparison to similar buildings was used to construct heat load characteristics (heat load regression lines) for each of the school buildings. The regression error was within ±2.8%, which was felt to accurately reflect variability.

### Post-Installation Data Collection

Energy consumption data for each building were collected during the heating season 1997-98. The heat consumption data, instant heating capacity, and water flows in the primary side were collected from the installed heat meter. Indoor temperatures were collected by permanently installed dataloggers (SmartReaders) in representative rooms. During each test, a manual reading of the indoor temperatures was also performed in classrooms and in hallways. Weighted average indoor temperatures were used for the energy efficiency calculations. Several times during the heating season, instant space heating capacity was verified by metering the heating water flow with a non-intrusive ultrasonic flow meter, and water temperatures. Correlation between the heat meter values and those obtained by the manual tests was found to be very good.

### Weather Data, Normalization

Weather data for Kyiv for the 1996-97 and 1997-98 heating seasons were obtained from the U.S. National Climatic Data Center. These data were used for both computer modeling and for normalization of the heat consumption in two heating seasons. The seasonal data from both seasons show only a slight deviation of degree days between the seasons.

### Indoor Conditions

In general, buildings in Kyiv are being underheated, as the district heating company provides supply heating water at lower-than-design parameters. Thus the indoor temperature is 1.5 to 2 C below the standard indoor temperature for schools. The efficiency improvement, calculated for both the actual indoor temperatures and for the standard temperatures, is shown in Table 3.

**Energy Efficiency Improvements**

The KIBA Technical Assessment predicted the energy efficiency for school buildings in a range of 23% to 26% of the baseline consumption. As shown in Table 3, the energy savings attained in the demonstration sites are in a range of 20% to 28%, thus showing a good correlation with predicted values. The best performance was obtained in school 272, as this school had the highest energy use intensity (EUI) prior to the installation. The other schools had a lower EUI than expected due to underheating. It is also important to note that the attained savings are relatively high due to a credit caused by lower heat input caused by restricting orifices persistently installed by the heating company, regardless of the fact that each substation is equipped with automatic control system regulating the heat input to the building.

**Table 3**. Energy Consumption Data and Efficiency Improvement for the Four Demonstration Buildings

| School Building | | **272** | **303** | **324** | **159** |
|---|---|---|---|---|---|
| Total heated floor area | $m^2$ | 8921 | 10301 | 5026 | 9511 |
| Average indoor temperature | C | 18.2 | 18.3 | 18.7 | 18.1 |
| Installed heating capacity | KW | 1300 | 1200 | 700 | 1000 |
| Design space heating capacity | KW | 813 | 604 | 354 | 536 |
| Baseline consumption 1996/97 | MWh | 1502.4 | 1050.4 | 675.8 | 1013.4 |
| Baseline consumption 1996/97, adjusted for standard indoor condition | MWh | 1668.4 | 1159.3 | 728.1 | 1132.2 |
| Baseline energy use intensity (EUI) | $Gcal/m^2$ | 0.145 | 0.088 | 0.116 | 0.092 |
| Adjusted baseline EUI for standard indoor condition | $Gcal/m^2$ | 0.161 | 0.097 | 0.125 | 0.102 |
| Metered consumption 1997/98, actual conditions | MWh | 1061.0 | 766.8 | 535.02 | 766.5 |
| Normalized 97/98 consumption for 96/97 weather data | MWh | 1074.8 | 776.8 | 541.0 | 774.4 |
| Normalized consumption 1997/98, adjusted for Standard indoor condition (20C) | MWh | 1193.5 | 857.3 | 582.9 | 865.2 |
| Normalized Energy Saving, Actual indoor condition | MWh | 427.6 | 273.7 | 134.8 | 239.0 |
| | **%** | **28.46** | **26.05** | **19.94** | **23.58** |
| Energy Saving, Adjusted for standard indoor condition | MWh | 508.1 | 324.6 | 156.9 | 292.4 |
| | **%** | **29.86** | **27.46** | **21.21** | **25.26** |

**Operation Experience**

This section presents the experience gained during the 97/98 heating season. The weatherization measures are termed passive in that once installed, there is no adjustment required. On the other hand, control measures are termed active in that adjustment may be required and periodic maintenance is required.

During the start-up period (the first 2 to 4 weeks) a number of service calls were required to clean the filters, bleed air from the system, and adjust the controllers.

**Operation and Maintenance Considerations**

- A higher level of service (‘handholding’) should be provided to recipients in the first year. Perhaps more service should be provided to recipients of installations in the first year coupled with training and a process to promote sharing of experiences.

- A training program for facility and building managers must be implemented.

- An incentive program should be considered to ensure persistence.

**Occupant Considerations**

- Expectations have to be managed because occupants were of the opinion that indoor temperatures would be higher as a result of the retrofits.

- Occupants should be polled at least in the first two years to better understand reactions so that implementation structures/processes can be modified to provide higher quality installations and promote acceptance.

# Conclusions

The following table summarizes the comparison of cost and energy efficiency values predicted by the KIBA Technical Assessment and results of the demonstration effort.

**Table 4**. Summary Estimated and Actual Cost and Efficiency Improvement by Building

| | Cost/m$^2$ | | Efficiency Improvement | |
|---|---|---|---|---|
| Building Number | Estimated | Actual | Estimated | Actual |
| 272 | $3.38 | $3.90 | 25.0 | 28.5 |
| 303 | $3.41 | $3.15 | 25.0 | 26.1 |
| 324 | $3.68 | $5.12 | 25.0 | 19.9 |
| 159 | $2.38 | $2.61 | 24.0 | 23.6 |
| Average | $3.36 | $3.67 | 24.8 | 24.5 |

The demonstration project was aimed at verification of predicted energy saving potential, estimated costs of installation, and as a learning experience for the implementation process. Without historical consumption data prior to implementation of the efficiency measures, it was difficult to establish a space heating energy consumption baseline. An alternative method based on comparison with other similar buildings and computer modeling was used to establish a baseline. It is believed that the energy saving evaluation is accurate and sufficient for the project purpose. The attained savings correlate well with the predicted values. The actual implementation costs are in a range of -7.5% to 38.9% and on average are 9.2% larger than the predicted costs. Cost savings due to higher volume installation, learning/training costs, and installation efficiencies are expected to reduce the cost by at least 10%.

The lessons learned from the implementation effort can be summarized as follow:

- The installation of some weatherization measures is weather dependent. The installation of all weatherization materials must take place in favorable weather conditions or the installation of weatherization materials must be phased to install those that are weather dependent under favorable weather conditions.

- Occupant education is required to prevent (or reduce) vandalism or other forms of occupant-related degradation of installed material.

- Training of installation contractors is necessary to ensure acceptable quality of installations.

- The length of time for the design process and approval points to a need to streamline this process and involve the district heating company.

- As part of the retrofit, cleaning of the secondary system within the building is a necessity.

- Heating system retrofits need to include valves in the risers and/or radiators to bleed air from the system.

- Follow-up service is needed to ensure correct operation of the system.

- A training program needs to be implemented to instruct facility/building managers on system operation.

- The district heating company must reconsider the sizing practices of the flow restricting orifices with regards to the automatic control equipment being installed in each building.