Energy Savings in Residential Multifamily Buildings–Demonstration Project in Kraków, Poland

Adam Gula, Fundacja na rzecz Efektywnego Wykorzystania Energii
(Polish Foundation for Energy Efficiency—FEWE)
George Reeves, George Reeves Associates, Inc.
Lawrence Markel, Electrotek Concepts
Richard F. Szydlowski, Battelle, Pacific Northwest Laboratories

The Kraków District Heat and Energy Efficiency Project was designed as a pilot program to demonstrate effective energy conservation strategies to improve air quality. Most of Kraków's heating energy is produced by coal burning, much of it in low stack, local boiler houses.

A demonstration project, aimed at determining potential savings of heat in typical multifamily residential buildings connected to the district heat network is described. Four identical multifamily buildings were selected for measurement and retrofitting. Together with the U.S. team, the local district heat utility, MPEC, the Kraków development Authority, BRK and the Polish Foundation for Energy Efficiency, FEWE, designed and conducted the 264 residence test of utility, building and occupant conservation strategies during the 1992-1993 winter. Baseline data were collected on each building prior to any conservation work. A different scope of work was planned and executed for each building, ranging from controls at the building level only to thermostatic valve control and weatherization.

The main result which follows from the data is that contrary to expectations, the addition of controls for the heating system at the building or apartment level, either by ambient temperature or by individual tenant actions, led to cost effective energy savings only together with the installation of inexpensive retrofit measures. First year results show that only small savings were achieved without such measures compared to about 20% when they were included. The measurement was continued over the 1993-1994 heating season with an extended scope of retrofit work, including external insulation of side walls. A twenty percent reduction in heating would be an enormous benefit to the Krakow air quality.

Introduction

The U, S. Agency for International Development's Krakow Clean Fossil Fuels and Energy Efficiency Project has, as a major component, a subproject designed to research energy efficiency in the Krakow district heating system. The municipal district heat utility, Miejskie Przedsiebiorstwo Energetyki Cieplnej w Krakowie (MPEC) purchases the majority of its energy from the combined power and heat plant Elektrocieplownia Kraków-Leg and is currently unable to expand due to pumping and piping constraints. In addition, a portion of the load is served by small local boiler houses. These are due to be shut down because of their extreme contribution to air pollution. Much of the design of the conservation project was negotiated between the U.S. and Polish teams, with the Polish side being led by the Kraków development authority, Biuro Rozwoju Krakowa (BRK) and strongly influenced by MPEC's needs. The retrofit work was carried out by technicians of the Polish Foundation for Energy Efficiency, Fundacja na rzecz Efektywnego Wykorzystania Energii (FEWE), following on-the-job training by U.S. conservation contractors. All data collection was performed by FEWE.

Base Conditions

The Buildings

Four adjacent "identical" buildings were selected for the project. The buildings are eleven stories high, with six apartments per floor, and have a basement storage area. The buildings have the same orientations and are located at numbers 4, 6, 8 and 10 Wolasa Street in the housing cooperative Zarzadu SM XXX-lecia. All floors in each building are identical. The building heating system consists of hot water radiators, generally piped vertically, with added heating intentionally supplied by pipe loops in bathrooms and foyers. Radiator sizing is adjusted for the calculated heat loss of each room, giving consideration to orientation, roof or floor loss, etc. The building heating energy source is the Krakow municipal district heat utility. The building plumbing is directly connected to the district heating plumbing loop, without any heat exchanger. Residents pay a fixed monthly price per square meter of floor area for heat, which is much below the actual cost. *There are no meters at either the apartment or the building level.* The cooperative pays MPEC based on the market rate times *calculated* heat loss and energy use, and receives a rebate from the state to cover the residents' subsidies. MPEC bills the cooperative for an installed radiator capacity of 423 kW. A 1987 MPEC study of the feasibility of improved building interface calculated the installed capacity as 419 kW.

The buildings are typical of post war construction in eastern Europe. Building elements are precast concrete slabs, assembled on site with not much precision. The wall slabs have hollow cores as shown in Figure 1, and are uninsulated resulting in a heat transfer coefficient of 1.15 W/m^2•K. This is equal to a U.S. R-value of just over 1.5, about equal to double glazing. Settling and initial construction errors result in occasional floor level changes in excess of 5 cm. Wood frame windows and balcony doors are poorly fitted to the concrete and often warp. Daylight is visible through many construction joints and smoke sticks are not necessary to find major air infiltration paths. A calculation of heat loss made for BRK included 84 kW for air infiltration. This is almost exactly 0.5 air changes per hour at the outdoor design temperature of -20°C, and we were advised that the basis was the building code requirement for ventilation. We suspect a much higher actual infiltration rate.

Building Temperature Control

There is no local temperature control, either at the room/apartment level or at the building level. There are no thermostats or other automated controls in any of the buildings. Manually operated valves exist on the radiators, but are frozen full open in most cases. MPEC controls its water temperature, at the Leg power station, based on outdoor air temperature, adjusted for cloud cover and wind speed. This results in a fairly sophisticated outdoor air reset strategy which aims to minimize customer discomfort. Additionally, serious problems at Leg resulted in much lower than requested supply temperatures during much of the pre-retrofit period. MPEC operates local sub-stations, however these generally have added pumping only, with no temperature control capabilities. The interface between MPEC and the building is via a venturi type device called a hydro-elevator. The hydro-elevator reduces the water pressure and induces lower temperature building return water into the building supply water line to reduce the supplied temperature. The amount of water induced increases as the MPEC supply pressure increases, preventing high temperature system water, 120°C, from entering the building plumbing loop. Figure 2 shows the hydro-elevator in schematic. The hydro-elevator orifice is set by MPEC to achieve a design building supply water temperature at the MPEC design supply temperature. Building water supply temperature is a function of MPEC temperature only; there is no control of the hydro-elevator.

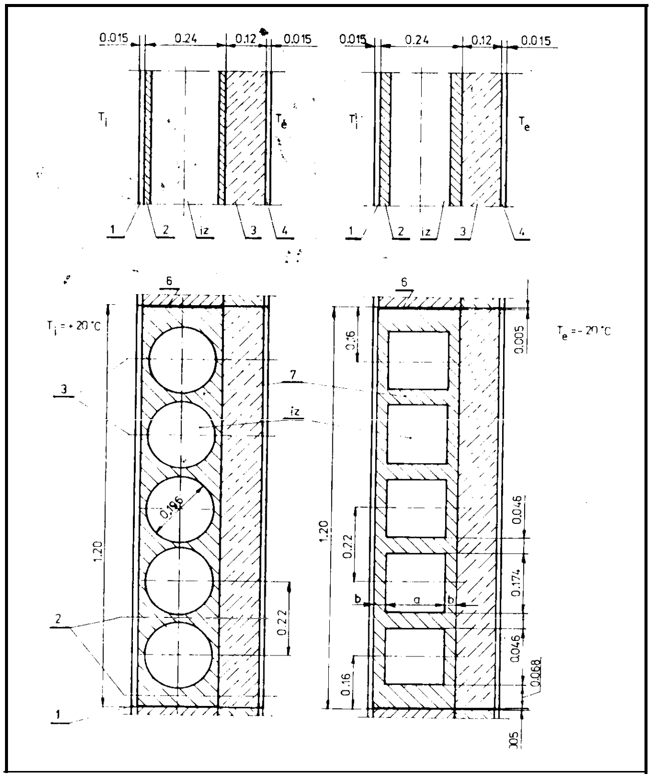

Figure 1. Typical Concrete Slab Element Construction

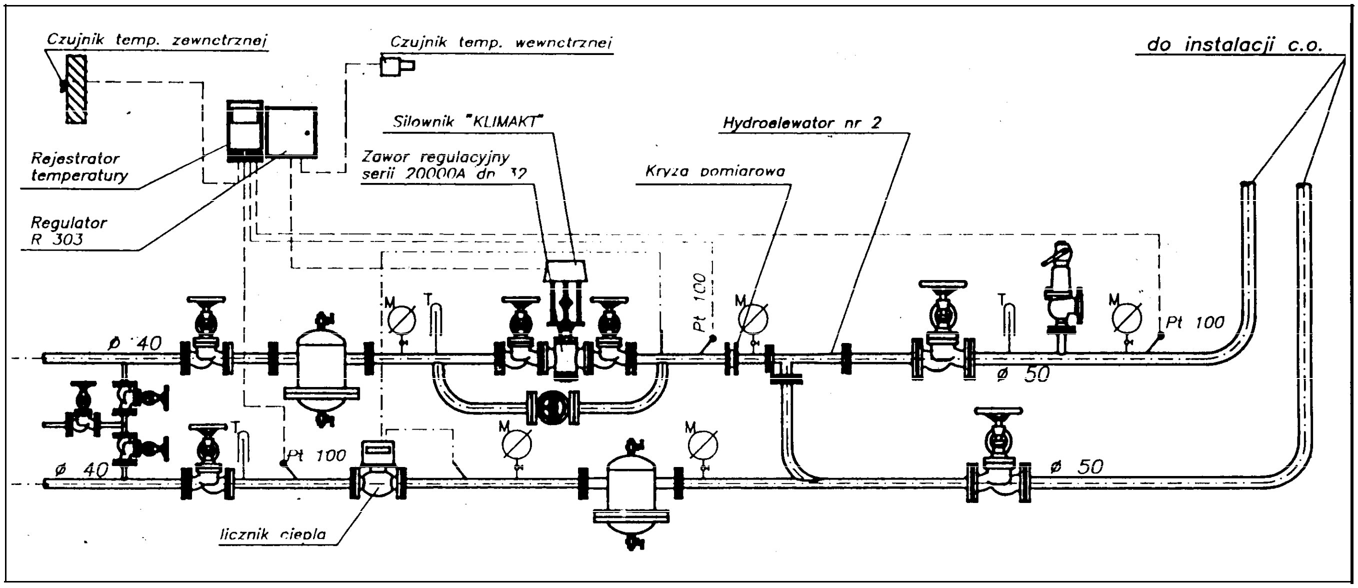

Figure 2. Hydro-Elevator Plumbing Arrangement at Building—District Heat Interface

Maintained Comfort

Near the winter average conditions of just above 0°C, where most of the winter hours are spent, the system works fairly well at keeping the residents warm. This is not just good fortune, but rather the result of a great deal of trial and error. At the extremes, things don’t work as well. In mild weather the system overheats the apartments substantially, due to the lack of thermostats. Occupant control of the heating system takes the form of opening windows. This type heating is so prevalent in Poland that open windows are ubiquitous above 5 to 10°C, even in modern glass curtain walled office buildings in Warsaw. Conditions during severe cold weather are poor. Heavy drapes are used to help block some of the breeze and radiant body heat loss, but these also serve to block the radiators, thus pouring much of the heat directly outdoors. The rooms are cold and uncomfortable. The high thermal conductivity of the walls, coupled with the small apartment size results in ice on the inside surfaces of some walls.

Conservation Approaches

The Polish and U.S. teams reviewed a wide range of possible approaches to higher building energy efficiency.

Improved Control

Improving heating control would do much to eliminate overheating, or occupant window opening as a control strategy. This could be accomplished in several ways. One method, outdoor air reset at substations, was not tested, due to cost. A second method, outdoor air reset at the building level was tested using two different interfaces. The third level of control is at the apartment level. Individual apartment thermostats were not tested because all the heating plumbing is arranged vertically, so control at the apartment level is not feasible. Therefore, individual room thermostats, mounted on the radiator supply lines, were tested in conjunction with rebates.

Provide Pricing Signals to the Residents

It was not feasible to test using a metered price per unit consumption, since the heating cost is highly subsidized. At the start of the project the typical apartment occupant paid about 22% of the actual heating cost. Instead, a system of rebates was set up based on metered usage, The rebates were tested in conjunction with thermostats and German manufactured “cost allocators” to measure the radiator output.

Structural Conservation Improvements

We reviewed low, medium and high cost conservation measures. Due to the desire to demonstrate applicability to all of Kraków’s multifamily construction, we concentrated on the low cost improvements. Measures were selected both on the basis of engineering estimates of cost effectiveness, and on the basis of comfort considerations, e.g., eliminating severe cold drafts. The measures included standard infiltration reduction techniques such as weatherstripping and caulking for all windows and balcony doors, replacement thresholds and door sweeps. Polish double glazing is separable for cleaning, so that joint was also weatherstripped. Attic insulation was easy to add. Basement ceiling insulation was very difficult, requiring concrete drilling. The calculated benefit was also very low, so it was demonstrated only.

Interior wall insulation was reviewed as a medium cost measure. It was judged not feasible, since it would result in further cooling of the floor/ceiling slabs, increasing the severe condensation/freezing problems.

Exterior wall insulation is the measure of choice in Poland for this style construction, but is very expensive. Due to the cost, and scheduling and experimental constraints, testing of this measure was postponed to the 1993-1994 heating season.

1992-1993 Winter Testing

Heat meters were installed in at the connection of each building to MPEC. All required plumbing changes were made before the beginning of the winter, and were arranged to be inoperable, with the exception of the metering. For example, the thermostat valve heads were removed. The buildings were operated in their normal fashion through December to collect sufficient metered data. Retrofits were performed in early January, and the remainder of the winter functioned as the post period.

Wolasa 4 was kept as a control building. An improved hydro-elevator, with outdoor air reset capability was installed, and the reset disabled for the base period. All other buildings had heat exchangers installed with outdoor air temperature reset and building pumps. Again, the plumbing was arranged so that they operated using the hydro-elevator in the base period.

Buildings 8 and 10 had thermostats installed on most of the radiators, and a rebate schedule was designed for the residents (Wisnewski and Reeves 1994). Building 10 received the weatherization package, installed by FEWE technicians following training by U.S. weatherization contractors.

The buildings were fully instrumented using a PC based system, and manual meter readings were made daily.

Analysis

The analysis methodology used was to extrapolate the measured building energy use to a typical Kraków winter of operation using a linear regression model. The base period had no control other than on the MPEC supply temperature. The variation in energy use in any building was thus a function only of the temperature of the MPEC supplied water and of the weather conditions. In essence the entire building can be viewed as a radiator providing a resistance to heat flow from MPEC to outdoors. The outdoor temperature was included as a separate term, rather than using temperature difference, to test whether the response to weather is different from the response to the supply temperature, caused by the different resistances to heat flow. Note that the MPEC supply temperature was controlled in response to outdoor air temperature, and so the separate outdoor air term will only pick up building response that was independent of the MPEC supply temperature. Tests of power fits were made since radiators in heated rooms transfer energy in proportion to T^K, where K ranges from 1.1 to about 1.5. These regressions gave no significant improvement over the linear model.

The post retrofit period has local control designed to be responsive to outdoor temperature in all four buildings. In addition, Wolasa 8 and Wolasa 10 have thermostatic control and will theoretically respond to heat loss. Ideally, then, energy use should be a function of outdoor temperature, and a PRISM type analysis would be appropriate. The MPEC supply temperature will, however, affect the energy used if the local control is not functioning. This occurred in two situations: when the MPEC supply was unable to deliver sufficient heat to satisfy the local control requirements, and during local control failure periods. Therefore the same two variable model should be tested for the post retrofit period.

The model used was a simple multiple linear regression of daily energy use against MPEC daily system average temperature and daily average outdoor temperature.

$$EnergyUse = F(T_{OutdoorAir}) + F(T_{MPECSupply})$$

There is a theoretical balance where the MPEC supply equals the indoor temperature and the outdoor air temperature is at the average balance point. PRISM would attempt to find that balance point, but is not capable of a two variable analysis. In addition, there is no operation of the system (or data collection) at outdoor temperatures above any reasonable balance point (18°C) or with the MPEC supply temperature below 55°C.

Therefore the equation estimated was:

$$E = \alpha_0 + \alpha_1 T_{OA} + \alpha_2 T_{MPEC}$$

Results

See Table 1 for the results of the regression.

Note that in all of the base case regressions, the outdoor air temperature coefficient is extremely small. In addition, the standard errors exceed the value of the coefficient,

Table 1. Two Variable Regression Results

Test Site	Period	R^2	Constant α_0 (GJ)	Outdoor Temp, α_1 (GJ/°C)	MPEC Temp, α_2 (GJ/°C)
# 4	Base	0.747	-8.03 (4.52)	-0.0648 (0.1088)	0.2892 (0.0527)
# 6	Base	0.822	-8.36 (3.50)	-0.0053 (0.0792)	0.2848 (0.0404)
# 8	Base	0.584	-7.89 (5.57)	-0.0197 (0.1292)	0.2837 (0.0645)
#10	Base	0.853	-9.29 (3.12)	-0.0531 (0.0731)	0.3052 (0.0361)
# 4	Post	0.962	1.28 (1.46)	-0.4398 (0.0491)	0.1819 (0.0168)
# 6	Post	0.972	-3.65 (1.11)	-0.1878 (0.0367)	0.2237 (0.0127)
# 8	Post	0.848	4.62 (2.88)	-0.5039 (0.0975)	0.1150 (0.0326)
#10	Post	0.955	4.96 (1.39)	-0.4616 (0.0468)	0.0967 (0.0157)

indicating that the coefficient is not significant. For example, the largest value, for building #4, is a result of only 0.648 GJ per day for a 10°C drop in outdoor temperature. In addition, the standard error on that value is ±1.088 GJ per day. It is apparent that the buildings are responding only to the MPEC supply temperature control. The outdoor air temp can thus be dropped from the regression, yielding the following results. Note that the estimate of annual use will be essentially unchanged since the outdoor air coefficient was very small, and the average winter outdoor air temperature is close to zero. See Table 2 for the one variable results.

Since the model is linear, the winter average energy use per day will equal the model result evaluated at the winter average outdoor air temperature of 1.55°C and MPEC supply temperature of 80.8°C. The data indicate savings for the four buildings as noted in Table 3.

Table 2. One Variable Base Period Regression Results

Test Site	Period	R^2	Constant (GJ)	MPEC Temp (GJ/°C)
# 4	Base	0.759	-10.160	0.315
# 6	Base	0.832	-8.554	0.287
# 8	Base	0.601	-8.592	0.292
#10	Base	0.857	-11.164	0.327

Discussion

Wolasa #4, with the addition of the regulated hydroelevator, allowing outdoor air reset, showed no savings. This could be because the radiator sizing combined with MPEC control at Leg is just as good as the local control. One possibility is that the Wolasa buildings are near the end of the MPEC supply lines and thus have less overheating. Since MPEC orders a new system temperature daily, it was also thought that the local control of the regulated hydroelevator would save energy by responding to the daily outdoor air temperature cycles. It may be however that the building's thermal mass is sufficient to eliminate the advantage of more frequent supply temperature control. A third possible explanation is that the control on the regulated hydroelevator was set too high, continuing overheating.

Wolasa #6 had a heat exchanger and outdoor air reset installed as a test of an alternate to the regulated hydroelevator. The results expected were similar to Wolasa #4, with possible improvement due to elimination of any diversions of system water. As with #4, the local control was evident in the significant values for dependence on outdoor air and reduced dependence on the MPEC supply temperature. Unfortunately, also as with Wolasa #4, the base and post usage are essentially the same, and no savings were found. The coefficient on the outdoor air temperature is much lower in this building, leading to speculation that the controller was not functioning correctly.

Wolasa #8 was retrofit with a heat exchanger and outdoor air reset controls, thermostats on almost all radiators and

Table 3. Energy Use and Savings Results

Building	Base Annual Average Use per Day, GJ	Post Annual Average Use per Day, GJ	Energy Savings
# 4	15.29	15.29	0.0%
# 6	14.64	14.13	3.5%
# 8	14.99	13.13	12.4%
#10	15.28	12.02	21.3%

cost allocators. In addition, rebates were paid to the occupants of the building based on their apartment energy use and on the building total energy use. This building did not maintain comfort conditions throughout the post retrofit period, having very cold spaces. Thus, a direct comparison is not possible. We can set a tentative upper limit on the savings due to pricing and thermostatic control of about 9%, the difference between the reductions at Wolasa #8 and Wolasa #6. Temperature recording show clear evidence of occupant thermostat use, and of thermostat control of flow and energy use. Other evidence clearly shows periods of full open thermostat operation with cold interior temperatures. We can speculate that perhaps half of the apparent savings are actually due to the combination of pricing and thermostatic control. It is not possible to estimate the effect of thermostats alone. (Pricing without thermostats would have no effect.)

Wolasa #10 was treated the same as Wolasa #8. In addition, the building was weatherized following a method previously found successful in the United States. The treatment included infiltration reduction methods, improvement of glazing, and attic insulation. The 21% savings were apparently real and due to the project. Based on comparison with the other buildings, we can conclude the weatherization saved a minimum of 9%. The actual value was higher than that for two reasons. First, Wolasa #8 was cold, and the pricing-thermostat savings are less than 9%. Second, the weatherization and insulation were not all completed before the beginning of the post period. In fact the analysis includes a significant number of days where the building was partially unweatherized. Note that weatherization has no effect if occupants open windows due to overheating in mild periods, so some control is necessary to achieve maximum savings. This, however could be at the building level.

Conclusion

Total cost of the weatherization package approximated the total first year savings on the MPEC bill. Cost including the building level improvements was about equal to the annual state subsidy to the apartments. These results are being review by BRK and both the local and federal governments to aid in legislation. Some form of conservation incentive is expected.

Project testing continues through the 1993-1994 winter, with the addition of weatherization to Wolasa 8, and of exterior insulation to both Wolasa 8 and Wolasa 10. FEWE has weatherized and monitored addition apartments in and around Kraków.

Reference

Wisnewski, R., and Reeves, G. 1994. “Energy Price Incentives in a Planned Energy Economy” Proceedings from the ACEEE 1994 Summer Study on Energy Efficiency in Buildings. American Council for an Energy-Efficient Economy, Washington, D.C.