UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT

Armenia School Boiler Replacement Study

Final Report

August 15, 2000

Submitted by:

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1.0 Introduction

Providing an economic and stable source of heat to public schools is a high priority for the Government of Armenia (GOA). Heating systems have for the most part not been functional since the early 1990's. Schools have relied on electric space heaters, wood and kerosene to meet heating needs since the shutdown of district heating systems due to inadequate natural gas supplies. The U.S. Agency for International Development (USAID) provided funding for distribution of kerosene to schools for several years on an emergency basis to keep schools open during the winter. In 1998, USAID provided funding for a study of school heating systems that reviewed needs and the state of current heating systems. This was done at a time when USAID was considering funding a program of installing gas-fired boilers in schools as an alternative to continuing the kerosene distribution program. The results of the study are documented in the report, "USAID Armenia School Boiler Project" (Contract #LAG-I-804-98-00004-00, TO #804), completed by Advanced Engineering Associates International (AEAI). USAID elected not to fund the school boiler program, and continued with the kerosene distribution program in 1998.

The Government of Armenia is now interested in financing a program of installing gas-fired boilers in schools, and has designated a total of $8 million over a three-year period, commencing with a $1 million pilot phase in 2000, and $3 million in 2001. The Government and the World Bank required assistance in prioritizing schools for selection, and a more detailed analysis of the costs and benefits of the program prior to commencing the work. USAID provided funding through a contract with AEAI for enhancing the original school boiler study to include the following:

1. Narrow the prioritized list of 200 candidate schools to the most feasible 40-50 schools in the first phase.
2. Expand the original school boiler feasibility study to include:
    a. Update of equipment costs and availability
    b. Financing requirements and analysis
    c. Administrative design for implementing the proposed program
    d. Project timeline and schedule
    e. Procurement plan recommendations
    f. Project risks and benefits
3. Present findings to USAID, World Bank and GOA officials.

The feasibility study site visits and analysis were conducted over the period June 10 – August 25, 2000. This report contains the results of the analysis and is the required deliverable on the Task Order.

2.0 School Selection

The USAID Armenia School Boiler Project Report gathered data on rural schools in Armenia, and ranked these schools according to the following criteria:

a. Existence of a functioning heating system
b. Availability of natural gas
c. Average winter temperature
d. Capacity utilization of school, expressed as number of students/volume

The study prioritized all rural schools for which there was data into the top 200 schools for inclusion in the possible USAID program. This analysis used these top 200 schools as a starting point for the selection of schools, with one important addition. In the meeting with the Ministry of Finance, Deputy Minister Safaryan requested that schools in Yerevan also be considered in the analysis. Yerevan schools tend to have higher heating costs since they rely on electricity for space heating in recent years. The Department of Education in the municipality of Yerevan was requested to provide a list of the top priority schools from their perspective, including only those schools not on a functioning district heating system. The Department of Education proposed a list of 67 schools for consideration. Both the prioritized list from the original study and the list of schools proposed by Yerevan Department of Education are included in Appendix A.

2.1 Selection Process

The selection process involved two stages: applying additional screening criteria to the schools in the original feasibility study and the schools suggested by Yerevan municipal education department, and a visit to each proposed school to assess its technical appropriateness. Between the two lists of schools, a total of 267 schools were suggested for consideration. Additional selection criteria that were used included:

- Yerevangas and ArmRusgas were asked to review the lists to verify that a natural gas connection was available within 500 meters of each school.
- The study focussed on two regions of Armenia from those covered in the original report: Shirak and Ghegarkunik. These two regions were chosen due to their being among the coldest in Armenia, and because a larger number of schools from these two regions were included in the prioritized list than any others. From the view of implementation also, it is better to focus activities in the first phase on a couple of regions to gain experience, and then expand to additional regions.
- In Shirak and Ghegarkunik, the lists were reviewed with the regional education departments also to get their recommendations.
- Natural gas is generally available in the Sevan and Ghegarkunik regions.

The above criteria when applied to the list of 267 schools narrowed the number for site visits to 78 schools. Each of the 78 schools was visited to select the most appropriate from a technical standpoint. A data collection form was developed to gather pertinent data regarding school capacity and utilization, physical characteristics, existing heating system, 1999-2000 energy consumption and other characteristics. Additional screening criteria applied after the site visits included:

- More than 600 students in the school in Yerevan; 500 students in Shirak and Ghegarkunik
- Capacity utilization higher than 70%
- Distance from main gas line is less than 500 meters – although the lists had been screened by ArmRusGas, this criteria was applied during the site visit as well since past experience had shown that the ArmRusGas estimate was not always current
- District heating not available or not sufficient

Each school was allowed to have one of the above criteria be negative, and still be included in the list of recommended schools. However, if more than one of these were negative, the school was eliminated.

2.2 List of Recommended Schools

Of the 78 schools visited, 53 are recommended for the first stage of the heating systems replacement program. The recommended schools are included in Tables 1, 2 and 3, for Yerevan, Shirak and Ghegarkunik, respectively. Several schools in Yerevan were also recommended for a subsequent stage, but these are not included in the list. Several schools on the list of Yerevan and Shirak schools are included on a special case basis (Schools #71 and #114 in Yerevan, Schools #110 and #137 in Yerevan, Schools #10 and #36 in Giumri). It is recommended that these paired schools have one boiler installed that would serve the two schools. This combination makes them suitable for inclusion on the list.

Appendix B contains the site visit reports for all of the schools recommended for Phase 1 of the rehabilitation program. The cost estimate for each school is also included in this Appendix. It should be noted that the cost estimate for each school includes a high efficiency German boiler, not the lower efficiency Russian boiler. This issue will be discussed in more detail in Section 3.0.

3.0 Technical Recommendations

There are several choices to be made on the extent of work that will be done on each of the schools to implement a new heating system. With a large-scale program such as is being considered by the GOA, and with the limited resources available, it is important that certain decisions be made up-front on the work to be done. Armenia is a country without fuel and energy resources, so these decisions must be made not only to solve a short-term problem of providing heat to schools, but also with a longer-term view towards future energy needs and energy security. This section presents the two most important trade-offs that will need to be considered.

During the former Soviet period, buildings were constructed with very poor thermal characteristics. As a rule, the thermal resistance of walls and roofs does not exceed 0,6-1,0m2oK/W. The values of heat transfer coefficient exceed 3W/m2oK. In the winter cold and summer hot climate conditions it causes extremely high heat loss and heat gains. The main energy being used for heating in recent years is based on electricity, which is generated by thermal and nuclear power plants. Currently, energy resources are being used in a most inefficient way and demand extremely high consumption of energy and fuel. Because of high price for electricity, all buildings and particularly schools are not properly heated. This influences the normal operation of schools and brings down the level of education.

For improving the classroom conditions and making heating less expensive, it's necessary to implement high efficiency heating systems. The greatest energy efficiency can be achieved by implementing the combination of following technical measures:

1. Reduction of heating loads by improving the thermal physical properties of buildings through weatherization and repair measures;
2. Use of higher efficiency heat generation and distribution systems. To maximize savings of energy and fuel, it's necessary to replace the existing low efficiency heating boilers by new efficiency boilers.

The majority of school buildings were connected to the district heating supply networks, however these systems have not operated since the early 1990's, and many are seriously damaged. Given the high cost and inefficiency of electric heat, it's becoming necessary to find longer-term solutions to heating in schools. Preliminary investigation and the installation of demonstration projects in Yerevan, Giumri and Spitak show that installing the combined technical measures of weatherization and high efficiency boiler will significantly reduce the cost of heating and create comfortable temperatures in the whole building.

This study analyzes six different scenarios, and compares the requirements for investments, annual energy and operating costs and energy savings:

1. Base Case – Heating existing building with electric space heaters of 1 KW, with an operating life of 3-5 years
2. Electric Heaters with Weatherization – same as base case, except weatherization is done which reduces heating load by about 20%

3. Installing Russian boilers with a typical efficiency of 80%, and an operating life of 10-15 years, in existing buildings
4. Installing Russian boilers with 80% efficiency and operating life of 10-15 years, combined with weatherization
5. Installing high efficiency German boilers with efficiency of 93%, and operating life of 20 years, in existing buildings
6. Installing high efficiency German boilers with efficiency of 93%, and operating life of 20 years, in combination with weatherization

Analysis of a Typical School

To illustrate the differences between each of the scenarios, one school (School #106 in Yerevan) was chosen as typical of the range of schools in the study. There are several schools in the list of recommended schools that are identical in size and design to School #106. There are also a large number that are similar in size, number of students and construction. Table 4 shows the conclusions of the analysis for School #106. Assumptions that were used in constructing the analysis are included in Appendix C, however it is important to note several items:

- The inclusion of weatherization allows for reduction in the capacity of the boiler by about 20%.
- The comparison case is using electric space heaters, and heating the building to design temperature of 20 C.
- It is assumed that natural gas is used in generating electricity for space heating. The analysis does not consider electricity generated from nuclear or hydro, since in the long-term, these resources may not be available in Armenia.

The comparison of investment cost and energy savings has some interesting elements. First, the majority of the savings come from switching from electricity to natural gas rather than the increased boiler efficiency if the Russian boiler maintains an 80% efficiency. Second, weatherization has fairly modest savings for the investment. However, this is because glass replacement is not included either in the weatherization cost or the savings. The study team was conservative on the estimate of gains from weatherization, since the focus of the study is on boilers. Weatherization alone allows for a substantial reduction in the size of the boiler, which is not adequately reflected in this table.

This analysis of a single school is not done on the basis of life cycle cost analysis, which takes into account the time value of money and the replacement costs of technologies with a shorter average useful life over the period. The life cycle cost analysis is presented in Section 5.0.

4.0 Regional and Total Financing Requirements

Similar to the analysis in the previous section for a typical school, the costs for schools in each region (Yerevan, Sevan and Giumri) were calculated for each school and then averaged for the region. The costs were grouped according to four categories:

- Weatherization – includes materials and labor costs for weatherizing windows and doors, and glass replacement
- Internal distribution network – includes material and labor cost for testing and replacement of radiators as necessary, and piping inside the building
- Boiler house – includes material and labor for construction or rehabilitation of boiler house, and connections to water, electricity, etc.
- Boilers – includes material cost for approximately sized boiler, and cost of shipping, automatic controls, burner, pressure stabilizer, insulation and installation. The boiler cost estimate is based on installing an imported German boiler COP of 93%.
- Gas and heat distribution line – includes material and labor cost for connecting boiler house to gas supply pipeline and connection between boiler house and school building for heat distribution
- Design estimate, permits – includes required design for construction of boiler house and connections to gas line.

Table 5 and Figures 1,2, and 3 show the results of the costing for each region and the averaging for schools within a region. The averages include the cost of an imported high efficiency boiler of German manufacture. If a Russian boiler of lower efficiency is installed, the cost estimates will be on the order of $15,000 to $20,000 lower per school. As shown in the energy analysis, the upfront cost will be lower but the operating cost will be higher due to lower operating efficiency. Section 5.0 of this report discusses this in more detail.

The data shows a substantial difference in cost between the regions. There are several factors that make up this difference:

- The weatherization cost for schools in Shirak region is substantially lower than for schools in the other two regions. This is because the schools in the Shirak region are on the whole newer, and some are of foreign construction with lower air infiltration rates than locally made and older windows.
- The boiler house cost in Yerevan is higher because many of the schools in the other two regions have an existing boiler house, while in Yerevan, the boiler house will be new construction.
- Gas and heat distribution pipeline cost is much higher in Yerevan because schools in the other two regions already have the distribution lines in place.
- In overall, the cost for the Shirak region is lower because the schools are newer.

5.0 Cost-Benefit Analysis

The data that was developed from the school visits, costing and energy analysis was input into a spreadsheet-based cost-benefit model for further analysis. This model was originally developed to analyze options for a demand-side management program in China. The model was adapted for use in this project to analyze the trade-offs between Russian and German boilers. Main features of the model include:

- Life cycle costing of the energy efficiency investment – This means that the investment costs and the savings are defined for the useful life of the equipment on a comparable basis. In this case, the maximum life is 20 years for the German boiler. During that period, the Russian boiler will need to be replaced at least once, since the useful life of the Russian boiler is 10-15 years. The electric heaters need to be replaced once every 3-5 years. The model allows the user to account for the varying useful lives by adding investment as the equipment needs replacing.
- Discounting of costs and benefits – The model allows the user to choose a discount rate that will reflect conditions in the economy, and brings the costs and benefits into present day terms for comparability. The model generates a net present value of the project, i.e. what the project is worth in today's terms given that the investment needs to be made today and the benefits are accrued over time in future years.
- Inclusion of both a private and a social discount rate – The private discount rate is essentially the time value of money. This is the idea that money loses its value over time. The social discount rate allows for the incorporation of externalities over time which also influence project costs and benefits but are not typically included in the cost of the project.
- Calculation of emissions from energy use and emissions reductions from switching to a more efficient technology. The model allows the user to define a generation fuel share, i.e. what percentage is from coal, nuclear, natural gas, other, and to calculate the emissions based on fuel share.
- Cost of emissions – The user can define the emissions reductions and then assign a cost per ton of emissions reduction. This incorporates the environmental costs or benefits of the project into the evaluation, including the net present value calculation and the calculation of the project's internal rate of return.

The results of the cost-benefit analysis show that by looking at the life cycle cost of both boilers, there is not much difference between the two in terms of money savings over the 20 year period. Given that the investment cost of the German boilers is so much higher, it is more rational to invest in the system with the lower up-front cost and be able to include more schools in the program. The assumptions used in the model are included in Appendix D. Figure 4 shows the cumulative net cash flow, NPV, IRR and discounted payback period for the two options.

6.0 Procurement and Implementation Recommendations

The Ministry of Economy and Finance was consulted concerning the most likely procurement arrangements for the School Boiler Replacement Program. Since this is considered to be a capital investment program, the decision on expenditure of the funds will be made by the Parliament. Based on the results of this feasibility study, the Ministry of Finance and the Ministry of Education will be able to submit a list of recommended schools for inclusion in the program. Parliament will approve the list and the amount for each of the schools in these three regions.

Once Parliament has approved the expenditure, the funds for the school improvements will be allocated to the Marz educational administration for spending. Each Marz will prepare a specification and scope of work for the various procurements. Government regulations require that any procurement utilizing government funds valued at over 2 million drams must be competitively bid. The Marz administration will prepare the bidding documents, issue the tender, and make the award, but the competitive bidding package and the award decisions must be approved by the Municipal Union.

It is recommended that the work be divided into the following components for competitive bidding purposes:

- **Weatherization work –** This procurement could include providing both labor and materials to complete the weatherization. There are several companies with substantial experience in this area.
- **Heating system design work –** It is important that a professional engineering design be completed for each site prior to construction work commencing. This will give the exact specifications for the work to be done at each site, including siting of the boiler house, location of the gas and heat lines, permitting requirements, etc. The design work should be done prior to preparation of the scope of work for any construction work.
- **Gas line construction –** Including both labor and materials to connect the main gas pipeline to the boiler house.
- **Boiler house construction, heat distribution system, internal distribution systems –** This work can be done by one contractor for each school.
- **Boiler procurement –** Once the decision is made concerning the type of boiler to be procured (Russian vs. German or other high efficiency type), it would make sense to procure the boilers in larger lots. A warranty contract should be negotiated that will provide at least three years warranty, and the possibility of an extended service contract. Each marz could procure their own boilers, or the three districts could combine forces to obtain the most favorable terms. Multiple bids should be sought for the boilers to get the best price.

A sample scope of work for weatherization is included in Appendix E. Other scopes will result from the engineering design work.

7.0 Implementation Schedule

AEAI and RMAr implemented a program in 1999-2000 of installing high efficiency boilers in combination with weatherization in four schools in Armenia. The experiences gained in that program concerning the time required for completing the project in each school may be useful to the GOA in planning. A sample schedule for the completion of one school that is based on AEAI's experience is given in Figure 5. The schedule shows each of the steps that is required in both boiler installation and weatherization work, and how much time each step is likely to require.

The schedules are only illustrative, however the boiler installation schedule shows the importance of beginning planning as soon as possible. The schedule illustrates that a six-month period is typical from the design of the heating system to completion of the installation. For the heating systems to be operational in the 2001-2002 school year, the design work should begin in February 2001. Careful planning is required to have the 50 schools completed in the desired timeframe.

The weatherization work schedule shows a typical time of 60 days for completing a school with 600 windows. Based on past experience, with an experienced company and a sufficient number of workers on-site, this is a reasonable time period for completion of the work. The weatherization work can take place at anytime in the spring to fall period, and can be scheduled with each school's administrator.

8.0 Environmental and Societal Impacts

8.1 Environmental Impacts of the Program

Overall, the project is expected to have positive environmental and societal impacts. The environmental impacts however, are mixed, depending on the source of fuel considered being replaced by natural gas. Natural gas-fired boilers will have lower emissions than first converting the natural gas to electricity, and then using the electricity for heating. If it is considered that kerosene or wood use is being replaced, then the air emissions are also reduced. If electricity from the nuclear plant is being replaced, the emissions will in fact increase, but overall environmental security will be increased. The GOA has pledged to shut down Medzamor in 2004, and finding alternative strategies to nuclear are a high priority, particularly for heating.

Environmental costs and benefits can be quantified, and should be in order for society to realize the full cost of alternative choices in setting energy strategies and policies. In this section, the environmental benefits of switching from kerosene/wood to natural gas use for heating are quantified. Using the same cost-benefit model, the inclusion of the environmental benefits raises the NPV of the project, and lowers the discounted PBP, as shown in Figure 6. The net cash flow is "social cost based" because it includes the externalities costs.

Insert two figures for Environmental Benefits

8.2 Societal Benefits

The implementation of the School Boiler Replacement Program will have several positive societal benefits as well:

- Provide a stable source of heating for schools that will enhance the educational opportunities for Armenian children. The average temperature in schools last winter was 10-12 C. This is not an environment that is conducive to learning.
- Many of the schools closed for an extended period last winter due to insufficient heat, interrupting the school year for a longer than normal period.
- Less possibility of illness contracted in the schools from the cold. Principals reported that parents kept their children home from school when the temperatures were very cold to prevent them from getting sick due to cold temperatures in the classrooms.
- Lower cost heat will mean that less money needs to be spent from the government budget at both the national and municipal levels.
- The Program will create employment opportunities for private companies engaged in providing energy services as well as manufacturers of the materials and equipment to be provided in the program.
- There is the possibility to assemble higher efficiency boilers in Armenia, in combination of automatic controls that are imported and boilers that are manufactured locally.
- The combination of weatherization and high efficiency boilers will reduce the overall reliance on imported fuels through increasing the efficiency of fuel use.

9.0 Project Risks

There are also risks involved in implementing the School Boiler Heating Systems Program as recommended. These risks include:

- **Technology Risk -** While the recommended technologies, especially high efficiency boilers, are technically and economically proven in other countries, they are not in widespread use yet in Armenia. The most sophisticated part of the boiler is the automatic control system. Training and warranties should be required of the equipment supplier as one of the terms of the procurement contract. Longer term warranties or service could also be negotiated.
- **Risk of No Water Supply (operating risk) -** The unstable water supply may cause some difficulty in boiler and heating system operation. This should be overcome with the use of water storage tanks for backup when water is not readily available.
- **Fuel (Supply and Price) Risk -** In the past, natural gas supplies have been unstable. It appears that the supply is stable for the near term future, however is natural gas use continues to rise and consumers are unable to pay their bills, the supplier will also be unable to pay for imports. The price paid at the border may also rise as demand rises. There is the risk that natural gas supply will be cut off either individually to the schools or to the country as a whole. If this happens, it is likely that the schools will go back to using kerosene, wood or electricity. The large expenditure of funds for this program will be wasted if the new heating systems suffer damage from being shut down during the cold months. The water in the distribution system will freeze, and the pipes will like burst.
- **Funding Risk -** Municipalities may not grant funding intended for school heating to the schools. The national budget contains a line item of per pupil for heating expenses for 2001. This budget should be passed along to the schools. However, some directors reported in the site visits that they had no allocation for heating in the winter of 1999-2000. Once the new boiler is installed, it must be kept operational, at least in a non-freezing regime, to avoid damaging the system.
- **Cost Overruns –** The study team was quite conservative in estimating prices for the installation at each school. There should not be a high risk of cost overruns.

One important way that some of the above risks could be mitigated is through training and educational efforts. A vigorous campaign to educate students, teachers and operational personnel should be implemented at the same time as the boilers are installed. Teachers and students should be educated to be aware of the cost of energy and how to avoid energy waste, by such means as keeping windows and doors closed and using the control valves in the classrooms if they get too warm. Perhaps the students could design publicity materials, and a contest sponsored for the best designs. Publicity about the program should be done so that the general public is aware of the expenditure for the school boiler program and for natural gas to fuel the boilers.

APPENDIX A

SCHOOLS CONSIDERED IN THE SELECTION

APPENDIX B

SCHOOL SITE VISIT REPORTS AND COST DATA

APPENDIX C

SCHOOL # 106 - YEREVAN

ENERGY AUDIT AND FEASIBILITY STUDY

ENERGY AUDIT CALCULATIONS

I .THE PURPOSE OF THE ENERGY AUDIT

The purpose of this energy audit was to evaluate the intensity of energy use and to identify the sources of inefficient use or waste of energy in the building. For these purposes, a detailed investigation of buildings of the school was completed.

The results of observations were used to rank biggest heat losses from the building and to recommend solutions based on economic paybacks. This school was selected for the detailed energy audit due to its typical design. Many schools built in Armenia in the 1970s have an identical design.

For evaluation of intensity of energy use, a survey was conducted. An audit questionnaire was developed, and included questions about number of pupils, number of rooms, classrooms, halls and schedule of work, number of teaching staff, number of people simultaneously in the school, distribution of people by blocks of the building, type of energy used for space heating, monthly electricity bill, bills payment conditions, etc.

II .THE RESULTS OF THE BUILDING AUDIT

1. SCHOOL BUILDING DESCRIPTION

Dimensions of the blocks of building:

School Building #1:	**School Building #2:**
Length A = 54m	**Length A = 30m**
Width B = 18m:	**Width B = 18m**
Height H = 9m	**Height H = 6m**
Floor area F = 972 sq.	**Floor area F = 540m**
Total floor area –2916 sq. m	**Total floor area – 1080 sq./m**
Volume – 8750 cub. M	**Volume – 3240 cub. m**
Surface of outside walls-1296 sq.m	**Surface of outside walls-576 sq.m.**

GYM and Conference Hall	**Corridor**
Length A= 30 m	**Length A= 30 m**
Width B =20m	**Width B= 12m**
Height H = 6m	**Height H = 3m**
Floor area F=600sq.m	**Floor area F=360sq.m**
Total floor area –600 sq.m	**Total floor area –360 sqm**
Volume–3600cub.m	**Total Volume–1080 cub. M**
Surface of outside walls-600 sq.m	**Surface of outside walls-252 sq.m.**

Building Envelope :

Roof area – 2472sq.m
Total external wall area – 2724 sq.m
Total glass area – 1400 sq.m
Total building volume – 16670 cub. m

The following types of windows exist in the school:

Types of windows	Sizes, m,	Surface,m^2,	Quantity	Total surface,m^2
1. double glazed,2sashes	2,9 x 2,2	6.38	150	957
2. double glazed,2sashes	2,15 x 1,5	3.22	46	148
3. double glazed,2sashes	1.8 x 1.9	3.42	3	10.26
4. double glazed,2sashes	1,9 x 1,9	3.61	21	75.81
5. single glazed	2.1x2.75	5.77	25	144.37

Total surface 1335 m^2

The following variety of types of doors exist in the school:

Types of the doors,	Sizes	Surface sq/m,	Quantity	Total surface sq/m
Single glazed,	2.9 x 2,8	8.12	8	64.96

Total surface 65 sq.m

- Total surface of glass on windows and doors - 1400 x 2 (layers) m^2
-Total surface of broken glass in - 2136 m^2

2.DESCRIPTION and THERMAL PROPERTIES OF THE SCHOOL BUILDING BLOCKS

a. Walls;

Construction material - from concrete panels,
Thickness - 0,20 m,
Heat conductivity of concrete panel - 0,80 W/m °C,
Heat transfer coefficient: - 1,49 W/m^2°C,
Total surface of the walls ΣF_w= 2724 m^2
State - sufficient.

b. Roof:

The construction of the roof of the block is made of concrete panels having a layer of insulation gravel over that and covered by cement plaster and hydro-insulation layer of rubberoid.
Heat transfer coefficient: - 0,60 W/m^2°C,
Surface - 2472 m^2

c. Windows:

The state of windows is poor. The frames of sashes are damaged. Many windows can not be properly closed because of warping. The total surface of windows is 1335 m^2. About 2136 sq.m. of glasses on both sashes of windows are broken. The gaps between the frames and sashes very often exceed 10mm. The flow of infiltration air through the gaps can be felt even by hand.
Heat transfer coefficient of double glazed wooden windows – 2,90 W/ m^2 °C

d. Entrance doors

The state of doors is not adequate from the point of view of infiltration of outside cold air. The frames are damaged. There are single glazed wooden and aluminum entrance doors in the building.
Heat transfer coefficient:

Single glazed, aluminum doors – 5,70 W/ m^2 ^oC

IV. INDOOR AIR CONDITIONS IN THE ROOMS OF THE SCHOOL

The heating of the rooms is very poor and not stable. According to the information of the director of the school, in many rooms (corner rooms and rooms with broken glasses) the inside temperature doesn't exceed 10^{o}C and in other rooms the temperatures are between 10-12^{o}C, (instead of 20 ^{o}C by standards). The expenditure for and the quantity of electricity allocated to the school is limited by the municipality. This limit is not enough for the normal heating of the school's rooms.

V. CLIMATIC CONDITIONS

The school #106 is located in Yerevan city which has rather dry and cold winter and hot summer. In Armenia the summer time is vacation period for pupils and the schools are closed. Therefore only the climatic conditions of winter time are reviewed.

- Design outside temperature for heating systems in Yerevan - 19^{o}C,
- Design inside temperature for schools +20^{o}C,
- Design relative humidity 40 – 60%
- Duration of heating period in Yerevan 3500 hours

VI. EXISTING HEATING SYSTEM

The school has a central water heating system with the design temperature of supply at 95^{o}C from a central boiler house and return at 70^{o}C. There are in use 120 electric heaters with 1000 W of capacity each. This number of heaters is not enough for installing them in all class rooms and offices

VII. EXISTING SYSTEM OF VENTILATION

On the top of vertical exhaust air ducts there are installed deflectors providing natural ventilation of rooms of the school. Visual observations showed that the system operates normally and provides standard quantity of outside fresh air which for schools corresponds to gv = 10 kg per person, per hour.

VIII. EVALUATION OF INFILTRATION RATE

The comparison of the state of windows and doors of the school with the windows and doors of Yerevan orphanage, elderly house, etc. buildings shows that their states are similar. In those buildings during 1994 – 1997 under the "Armenia Weatherization Program", a typical outside air infiltration flow rate was determined. On the basis of this comparison, and taking into account the rather large surface of broken glass, it is concluded that the infiltration rate for the school could equal g_{inf} = 0,0018 kg per second, per 1m^2 of glazed surface. The infiltration rate for the weatherized windows is estimated to be g_{inf} = 0,0006 kg per second, per 1m^2 of glazed surface.

IX .THE RESULTS OF THE BOILER HOUSE AUDIT

The school does not have a boiler house.

X. DETERMINATION OF HEATING LOAD FOR THE EXISTING CONDITIONS OF THE SCHOOL BUILDING

The heating load of the school building or installed thermal capacity of the heating boiler is determined by the following sum of heat loss and heat gains:

$$Q_{h.l} = Q_l + Q_v + Q_{inf} - Q_{int}$$

where: $Q_{h.l}$ - *heating load of the building, kW*
Q_l - *heat lost through the external constructions of the building,kW*
Q_v - *quantity of heat needed for heating the ventilation air from the temperature of outside air to the temperature of inside air, kW,*
Q_{inf} - *quantity of heat needed for heating the ventilation air from the temperature of outside air to the temperature of inside air, kW,*
Q_{int} - *heat gains from the Internal heat sources, kW.*

1. Calculated value of heat loss

Heat loss, Q_l, from the building takes place through the external constructions – walls, windows, doors and roof. The total value of heat loss is determined by the following formula:

$$Q_l = Q_w + Q_{ww} + Q_r$$

Q_w – Heat lost through the walls
Q_{ww}- Heat lost through the windows
Q_r – Heat lost through the roof

a.The quantity of heat loss through the walls Q_w is calculated by the formula of heat transfer:

$$Q_w = k_w SF_w (t_{ins} – t_{out})$$

b. The quantity of heat loss through the windows is calculated by the formula:

$$Q_w = k_{w\,w} SF_{ww} (t_{ins} – t_{out})$$

c. The quantity of heat loss through the roof is calculated by the formula:

$$Q_r = k_r SF_r (t_{ins} – t_{out})$$

2. Calculated Value of heat Q_v , needed for heating the ventilation air

The value of the heat quantity Q_v, kW, needed for heating the ventilation air from the temperature of outside air to the temperature of inside air, can be calculated by the following formula:

$$Q_v = m\, g_v C_{air} (t_{ins} – t_{out})$$

3. Calculated Value of heat Q_{inf} , needed for heating the infiltration air

The quantity of heat Q_{inf} , kW, needed for heating the infiltration air from outside temperature to the temperature of inside air, is calculated by the following formula:

$$Q_{inf} = g_{inf} C_{air}\ F_{ww}(t_{ins} – t_{out})$$

4. Calculated value of internal heat gains

The value of heat quantity Q_{int},, kW, rejected from the building occupants can be calculated by the following formula:

$$Q_{int}, = m\ q$$

where: m = 760 – number of people simultaneously being at schools,

q = 116 W per person per hour – quantity of heat rejected from each person.

For existing conditions (without weatherization)

Using the formulas and values for parameters described above, the quantity of heat loss and gain through the construction of all blocks is calculated:

Walls Qw = 1.49 W/sq.m C x 2724 sq.m x (20-(-19))=158290 W , or
Qw = 158,3 kW

Windows Qww = 2.9 W/sq.m C x 1400 sq.m. x (20-(19))=158340W , or
Qww = 158,3 kW

Roof Qr =0.6 W/sq.m. C x 2472 sq.m. x (20-(-19))=57844 W, or
Qr = 57,8 kW

The total value of heat loss : Q_l *=158,3 + 158.3 + 57.8 = 374.4 kW*

2. Calculated Value of heat Q_v , needed for heating the ventilation air

m = 760: g_v = 0,0028 kg per person per second: C_{air} = 1,003 kJ/kg^{o}C .
For the mentioned values, the heat quantity Q_v, kW, equals:
Q_v = 760 x 0.0028 kg/sec x 1.003kJ/kgC x (20-(19))=83,*24 kW*

3. Calculated Value of heat Q_{inf} , needed for heating the infiltration air from non weatherized windows

g_{inf} = 0,0035 kg per second, per 1m^2 of glazed surface. F_{ww} = 1400m^2 ; *Cair* = 1,003 kJ/kgoC.

For the mentioned values the heat quantity Q_{inf} , kW, is equal to:
Q_{inf} *= 0.0018 kg/sec sq.m. x 1.003kJ/kgC x 1400 sq.m. x (20-(-19))=98.6 kW*

3. Calculated Value of heat Q_{inf} , needed for heating the infiltration air weatherized windows

g_{inf} = 0,0035 kg per second, per 1m^2 of glazed surface. F_{ww} = 1400m^2 ; *Cair* = 1,003 kJ/kgoC.

For the mentioned values the heat quantity Q_{inf} , kW, is equal to:
Q_{inf} *= 0.0006 kg/sec sq.m. x 1.003kJ/kgC x 1400 sq.m. x (20-(-19))=32.9 kW*

4. Calculated value of internal heat gains

m = 760: q = 116 W per person per hour.
For the mentioned values the heat quantity Q_{int},, kW, is equal to: Q_{int} *= 760 x 116 W=88.16 kW*

Calculated value of design heating load without weatherization:

$Q_{h.l} = Q_l + Q_v + Q_{inf} - Q_{int}$ *= 374.4 + 83.24+ 98.6 – 88.16 =* <u>*468 kW*</u>

Taking into account a 10% reserve (reserve of outside climatic conditions and heat lost through basement) the design heating load of the school building will be equal to:

$Q_{h.l}$ = 1,1 $Q_{h.l}$ = 1,1 x 468 = 515 kW

5. Evaluation of Seasonal Heating Load of the School Building Without Weatherization

The seasonal heating load for the school is calculated taking account the above mentioned existing conditions, thermal physical data, broken glass, dimensions of external construction of the building and heating degree– hours for Yerevan. By special calculation, it is determined that for inside air temperature equal to +20oC, the degree-hours for Yerevan is equal to DH = 65025^{o}CH. So, the seasonal heating load of the building can be calculated by the following formula:

$Q_{h.l.ses.} = (k_w\, SF_w + k_{w\,w} SF_{ww} + k_r SF_r + m\, g_v\, C_{air} + g_{inf} C_{air}\, F_{ww})$ x $DH – mq$ x 3500 : 3 *(people are in the school only 1/ 3 of the 3500 hours heating period).*

By substituting the values for existing conditions of the school building in the last formula the following seasonal heating load $Q_{h.l.ses}$ is determined:

$Q_{h.l.ses}$=*[(1,49x2724+ 2.9 x1400+ 0,6x2472):1000+760 x0,0028x1+ 0,0018x1x1400] x 65025 –760 x 116:1000 x 3500 : 3 = (9.6 + 2.12 +2.52) x 65025 - 102853=925956 – 102853= 824657*

The total seasonal heating load of the school building without weatherization equals:

$Q_{h.l.ses}$ = 824657 kWh per season

6. Calculated value of design heating load of the school building with weatherization of windows and doors

Weatherization of the windows and doors of the building will eliminate the quantity of heat required for heating the infiltration air

$Q_{h.l} = Q_l + Q_v + Qinf - Q_{int}$ = *374.4,3 + 83.24 +33 – 88.16 = 402.7 kW*

Taking into account a 10% reserve (reserve of outside climatic conditions and heat lost through basement) the design heating load of the school building will be equal to:

$Q_{h.l}$ = 1,1 $Q_{h.l}$ = 1,1 x 402.7 = 443 kW

7. Evaluation of seasonal heating load of the school building with weatherization of windows and doors

The seasonal heating load of the school building with weatherization of windows and doors can be determined by the same formula, assuming $g_{inf} = 0$. The value of seasonal heating load can be calculated by the following way:

$$Q_{h.l.ses..w} = (k_w\, SF_w + k_{w\,w} SF_{ww} + k_r SF_r + m\, g_v\, C_{air} + g_{inf} C_{air}\, F_{ww}) \text{ x } DH - mqx3500:3$$

On the basis of values in the formula:

BLOCK # 1

$Q_{h.l.ses}$=*[(1,49x2724+ 2.9 x1400+ 0,6x2472+0.0006x1x1400):1000+760 x0,0028x1] x 65025 –760 x* *x 116:1000 x 3500 : 3 = (9.6 + 2.13) x 65025* **-** *102853=762743 – 102853= 715087*

The total seasonal heating load of the school building without weatherization equals:

$Q_{h.l.ses}$ = 715087 kWh per season

XI. EVALUATION OF HEATING SYSTEMS THERMAL CAPACITIES AND ENERGY CONSUMPTION FOR THE SCHOOL BUILDING'S HEATING

1. Calculated total capacity of electric heaters and seasonal electricity consumption for electric heating of the school building in existing conditions

Presently the blocks of the school building are heated by electricity. According to the above heating load calculations, for normal heating of all rooms of the school, the installed total electric power of electric heaters should be equal to 515 kW. In other words, for normal heating of the school, 515 electric heaters with 1kW of power each would be required. Instead of 515, there are only 120 heaters installed in classrooms and some offices. This is the reason for extremely low temperatures in the rooms during the heating season.

In case of electric heating, the electricity consumption during the heating season is equal to the seasonal heating load in kWh, which, as calculated previously, makes $Q_{h.l.ses} = 824657$ *kWh per season*.

2. Calculated Value of Installed Thermal Capacity of RUSSIAN Boiler and seasonal gas consumption for heating of the school building in existing conditions (without weatherization)

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The installed thermal capacity of the boiler must be equal to the design heating load of the building:

$$Q_b = Q_{h.l} = 515\ kW$$

The seasonal gas consumption by the boiler depends on the seasonal heating load and the COP of the boiler, and is calculated by the following formula:

$$B_{ex.b} = Q_{h.l.ses} \times 3600 : Q_{gas} : COP$$

where: $B_{ex.b}$ – seasonal gas consumption, m^3 per season,

$Q_{gas} = 35500$ kJ/ m^3 – specific heat of incineration of natural gas,

With these values, the seasonal gas consumption for heating by the new Russian typical efficiency boiler (COP=0,80) in existing conditions of the school building ($Q_{h.l.ses} = 977862$ *kWh per season)* is:

$$B_{ex.b} = 824657 \times 3600 : 35500 : 0{,}8 = 104534 \text{ cub.m. per season}$$

$$\mathbf{B_{ex.b} = 104534\ cub.m.}$$

Calculated Value of Installed Thermal Capacity of the High Efficiency Boiler and seasonal gas consumption for heating in case of existing conditions (without weatherization) of the school building

In case of installation of high efficiency boiler with COP = 0, 93, in existing non-weatherized conditions of the school building, the installed thermal capacity Qb , of the boiler again is $Q_b = 515\ kW$. Seasonal gas consumption by the high efficiency boiler for heating of the school building in existing non-weatherized conditions (Qh.l.ses=824657 kWh per season*)* by new efficient boiler (COP=0,93) is:

$B_{ex.b}$ = 824657 x 3600 : 35500 : 0,93 = 89922 cub.m. per season

$B_{ex.b}$ = 89922 cub.m.

4. Calculated Value of Installed Thermal Capacity of the RUSSIAN Boiler and seasonal gas consumption for heating with weatherization of the school building

With weatherization and rehabilitation of existing boiler with COP = 0,8 the installed thermal capacity Qb , will be equal to the design heating load *Qb = 443 kW*.

The seasonal gas consumption for heating of the school weatherized building (*$Q_{h.l.ses}$ = 715087 kWh per season*) by the low efficient boiler with COP = 0,8 is:

$B_{ex.b}$ = 715087 x 3600 : 35500 : 0, 8 = 90645cub.m. per season

$B_{ex.b}$ = 90645 cub.m.

5. Estimated Value of Installed Thermal Capacity of the High Efficiency Boiler and seasonal gas consumption for heating with weatherization of the school building

With weatherization and installation of new high efficiency boiler with COP = 0, 93, the installed thermal capacity Qb , will be equal to the design heating load *Qb = 443 kW*.

The seasonal gas consumption for heating of the weatherized building (*$Q_{h.l.ses}$ = 715087 kWh per season*) by the new high efficiency boiler with COP = 0, 93 is:

$B_{ex.b}$ = 715087 x 3600 : 35500 : 0,93 = 77974cub.m. per season

$B_{ex.b}$ = 77974 cub.m.

XII. INSTALLATION, ENERGY AND ANNUAL OPERATIONAL COSTS FOR VARIOUS HEATING SYSTEMS

Existing Electric Heating Without Weatherization of the Building

a. Investment Cost of Electric Heaters

According to market prices in Yerevan, the cost of electric heaters with their installation in the cast-iron type radiators of water heating systems is at least $25 per kW of heaters. Therefore, the total cost of the electric heaters installed in the school is: $25 x 515 = $ 12874.

b. Energy Cost

The tariff for electricity in Yerevan is $0,05 per kWh. Therefore, the cost for electric heating of the school building without weatherization (Qh.l.ses = 824657 kWh per season*) is*:

Z_e = 0,05$/ kWh x 824657 kWh = $ 41232 per season

c. Operation Cost of Heating System

The operation cost of the heating system is the sum of annual salary and expenses for current reparations. It is assumed that there is no need for operating personnel or salary for the use of electric heaters.

Existing Electric Heating With Weatherization of the Building

a. Investment Cost of Electric Heaters

According to market prices in Yerevan, the cost of electric heaters with installation is at least $25 per kW of heaters. Therefore, the total cost of the electric heaters installed in the school is: $25 x 407= $ 10163.

b. Investment Cost of Weatherization

The implementation cost of weatherization of the windows and doors is - $27300.

The life cycle of the weatherization is 35 years.

c. Energy Cost

The tariff for electricity in Yerevan is $0,05 per kWh. The cost for electric heating of the school building without weatherization (Qh.l.ses = 715087 kWh per season*) is*:

$$Z_e = 0{,}05\$/\text{ kWh} \times 715087\text{ kWh} = \$\ 35754 \text{ per season}$$

d. Operating Cost of Heating System

The operating cost of the heating system is the sum of annual salary and expenses for current reparations. It is assumed that there is no need for operating personnel or salary for the use of electric heaters.

RUSSIAN 80% Efficient Boiler Without Weatherization of the School Building

a. Investment Cost of Russian Boiler

According to the spare parts and job market prices in Yerevan the estimated cost for the installation of a 515 KW Russian-made boiler is - **$12800** .

According to the supplier, the average useful life is 10 years.

b. Energy Cost or Cost of Consumed Gas per Season

The cost for 104534 cub.m gas, consumed for heating of the school non-weatherized building (Qh.l.ses = 824657 kWh per season*) i*s:

$$\mathbf{Z_g = 109\ \$ \times 104534 / 1000 = \$\ 11394 \text{ per season}}$$

c. Operating Cost of Heating System

It is assumed that for the operation of the boiler, the salary for 4 operating personnel will be $2500 per year. According to the existing norms for current reparations of the boilers, expenses for maintenance are assumed to be 10% of the implementation cost, equal to $1280 per year. So, the operation cost of existing boiler heating system is equal to **$3780 per year.**

RUSSIAN 80% Efficient Boiler With Weatherization of the School Building

a. . Investment Cost of Russian Boiler and Weatherization of the Building

As shown above the estimated cost for the Russian boiler is - $12800
The investment cost of the weatherization of windows and doors is - $27300.
The total cost for implementation of this combined heating system is: $40100

The useful life of the weatherization is 35 years and boiler is 10 years.

b. Energy Cost or Cost of Consumed Gas per Season

The cost for 90645 cub.m gas, consumed for heating of the school weatherized building (Qh.l.ses = 715087kWh per season*) is*:

Zg = 109$ x 90645 /1000= $ 9880 per season

c. Operating Cost of Heating System

As calculated above for the operation of the boiler, the salary of 4 operating personnel will be $2500 per year and expenses for current maintenance of the boilers are: $1280 per year.

So, the total operating cost of the existing boiler heating system is equal to **$3780 per year.**

High Efficiency (93%)Boiler Without Weatherization of the School Building

a. Investment Cost of High Efficiency Boiler

According to the price-lists of German manufacturer VISSMAN catalogue and market prices in Yerevan, the estimated cost for the installation of an efficient boiler with COP = 0,93 and capacity 520 kW is   - $ 35532

According to the catalogues of Western producers the average life cycle of high efficient boilers is 20 years.

b. Energy Cost or Cost of Consumed Gas per Season

The cost for 89922 cub.m gas, consumed for heating of the school's non-weatherized buildings (Qh.l.ses = kWh per season*)* is:

Zg = 109$ x 89922 /1000= $ 9801 per season

c. Operating Cost of Heating System

Because of a fully automatic control system, it is assumed that operation of the high efficiency boiler requires only 1 operating personnel with a $700 annual salary. According to experience, expenses for current reparations of these boilers does not exceed 5% of the implementation cost, or $1776 per year. So, the total operation cost of efficient boiler heating system is equal to: $700 + $1776 = $2476 per year.

5. High Efficiency Boiler With Weatherization of the School Building

a. Investment Cost for High Efficiency Boiler and Weatherization

According to the price-lists of Companies catalogues and job market prices in Yerevan the estimated cost for the installation of an efficient boiler having COP = 0,93 and capacity of 407 kW would be   - $28201

The implementation cost of weatherization of windows and doors is evaluated to be - $27300. The total cost of the implementing the combined measures would be: $55501

According to the catalogues of Western manufacturers, the average useful life of high efficiency boilers is 20 years. The useful life of the weatherization is 35 years.

b. Energy Cost or Cost of Consumed Gas per Season

The cost for 77974 cub.m gas, consumed for heating of the weatherized building (Qh.l.ses = kWh per season*)* is:

Zg = 109$ x 77974 /1000= $ 8499 per season

c. Operating Cost of Heating System

As used above for the operation of the boiler, the salary of 1 operating person will be $700 per year . The expenses for current maintenance of the boilers do not exceed 5% of the implementation cost, or $1410 per year. So, the operation cost of existing boiler heating system is equal to:

$700 + $1410 = $2110 per year.

All the results of above calculations including savings of quantity and cost of electricity and gas per season are represented in the following table.

APPENDIX D

COST-BENEFIT ANALYSIS CALCULATIONS

APPENDIX E

SAMPLE SCOPE OF WORK FOR WEATHERIZATION