HUMBOLDT STATE UNIVERSITY

Sunnybrae Middle School: Heating System Options

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Table Of Contents

Problem Statement:

A particular boiler in question at Sunnybrae Middle School operates at an estimated 50% efficiency; compared to the average 75% efficiency of most modern heating systems, therein lays room for improvement.

Background:

Due to both budget constraints and an increasing environmental awareness in our community, efforts are being made to increase energy efficiency, and consequently decrease energy costs, in Arcata's schools. These cost savings can in turn be used for more vital functions within the schools, such as purchasing new textbooks, hiring new teachers and funding after-school programs, to name only a few. Increasing efficiency also reduces the use of fossil fuels and results in lower emissions of greenhouse gases.

Traditionally, two roads can lead to increased energy efficiency – technological modifications and behavioral modifications. Although both must be addressed in order to curb consumption, the latter tends to be a slippery solution that requires continuous monitoring and refining; it is the proverbial teaching new tricks to an old dog. Again, behavioral modifications should always be encouraged, but the benefits to such efforts are often spread out over time and people, resulting in less accountability. Technological changes, on the other hand, tend to have a more quantifiable and indeed more predictable outcome in terms of costs and benefits.

According to Mike Osborne, Director of Maintenance, Transportation and Operations of the Arcata school district, a major concern currently is the boiler system at Sunnybrae middle school. The boiler operates at an estimated 50% efficiency; compared to the average 75% efficiency of most modern heating systems, therein lays room for improvement. Yet the problem is not limited to the efficiency of the boiler itself.

Also an issue is heating distribution. The boiler in question at Sunnybrae is set up in such a way that rooms are usually either too hot or too cold, but a comfortable median is not often reported. This is possibly due to the fact that the boiler operates on its highest settings from 7AM until 11AM, when the rooms become too hot. This awkward arrangement contributes to a wide range of quality in terms of desired heat specifications for the classroom environments.

Since the school system's budget is on a downturn, funding and payback periods will be of vital significance to when and how increased efficiency can occur. This aspect of the problem will determine parameters of possible solutions ranging from total HVAC replacement to modifying the current boiler system in order to make it more efficient. Although additional funding should be sought outside of the school system to increase efficiency, possible alternatives to the current situation will not be discarded because of the present lack of such aid. The most important result of any effort is that energy efficiency is increased while also creating for students and teachers an environment which is conducive to learning.

Building Description:

The existing heating system consists of one boiler installed during the construction of the facility, approximately thirty years ago. The system uses the piped hot water through regularly spaced radiators to distribute heat to the library and two, one story buildings (see appendix 1, site sketch). Building one has a volume of 68722 ft^3, which is partitioned into six separate spaces at 11453 ft^3 per room. Building two has two rooms at 17127 ft^3 per room, which adds up to a total of 34254 ft^3. The library has a volume of 20493 ft^3. All buildings added up, the boiler provides heat for 123,469 ft^3. A wall perimeter of about 663 ft would be accounted as pipe length. A non scale bird's eye view of the buildings described can be seen in appendix 1.

Building Name	Rooms	Area
Complex (building 1)	6	68722 ft^3
Home Economics (building 2)	2	34254 ft^3
Library	1	20493 ft^3
Total	9	123,469 ft^3

Goal:

Our goal is to offer alternatives which increase efficiency of the HVAC system at Sunnybrae Middle School.

Objectives:

Our objectives are to offer solutions which accomplish the following:

1. Increase efficiency of the HVAC system from the current 50% to a minimum 60% efficiency.
2. Any alternative will pay for itself within a twenty-year period of time.
3. Create a balanced range of temperature that can be equally distributed to all the rooms.
4. Meet Arcata's emission reduction plan, and reduce green house gas emissions by a minimum of 7%.

Alternatives:

As it was addressed in the problem statement and history, Sunnybrae's current boiler provides at best an inefficient source of bulk heat that can not, or has not, been tuned to the needs of the school complex. The alternatives fall into two major categories: replace the boiler with another heating source or adjust the boiler and complex to be more energy efficient and provide a more comfortable room temperature throughout the affected areas. Also a priority for any alternative is that it must, to the greatest degree possible, meet our goal and objectives. Following are the alternatives which we have chosen to consider in detail.

Alternative 1:

Modify the boiler through automation, closer monitoring and minor adjustments in water temperature and insulation. This would require thermostats to be replaced in classrooms so staff and faculty can monitor both the settings as well as the current temperatures. Automated timers and settings would be installed on the boiler to provide seasonally appropriate temperatures and duration of boiler operation. Also, each radiator would be equipped with a hood so as to push air into the lower reaches of the rooms, rather than the set-up of current radiators which send the heated air to the top of the rooms, making it less effective in heating the occupied space. To improve the insulation of the rooms would also decrease the amount of heat that would be required to maintain a comfortable environment.

Alternative 2:

Replace the boiler with a new, more efficient boiler. This alternative will not consider replacing pipes, but upgrades to some radiators may be desirable. Automated settings and thermostats would be installed to ensure that desired temperatures could be achieved throughout the complex.

Alternative 3:

Replace the boiler with forced-air systems. This alternative would involve installing one natural gas powered forced-air heating unit per two classrooms, as well as one other that would provide the library with its own heat source. This is the same set-up that prior retrofitting of other classrooms on the premises have utilized. New ventilation ducts would also be required, as well as thermostats to control the heat level and to run the system at an efficient rate.

Alternative 4:

A last alternative would be to replace the current boiler with a natural gas cogeneration unit. This would be a replacement or supplemental heat source as well as electrical source. Grid inter-tie will be preferred, although units can also provide stand-alone power.

Implementation:

In order to select an alternative to Sunnybrae Middle School's current boiler-source heating system, at least three questions must be answered.

What heating system would replace the boiler? How will each alternative benefit Sunnybrae? What are the costs and returns on investment associated with each alternative? To address these questions, each alternative has been laid out in terms of what is entailed in the implementation.

Structure Enhancements:

Since any of the alternatives require high installation costs and potential increased maintenance costs, looking at the possibilities of the present system is important for this research. The possibilities would range from behavioral changes to basic structural enhancements. Some of the behavioral changes would involve looking at the present operation of the boiler, the way the temperature is programmed and the hours of operation. It would also look at the class use of the heating units. Some of the aspects would include: obstruction of the heating vents, classroom set up and operation of the ventilators that blow the air out of the heating unit. The structural part of it would involve minor changes to the structure of the building to increase the heating and cooling properties as well as reducing the heating waste. Some of the enhancements would range from adding insulation, to changing the windows and re-installing the thermostats in the classrooms. All the alternatives would include a cost/benefit analysis contrasting the installation and equipment costs to the actual enhancement of the cooling and heating properties of the rooms, and how that would reflect on the overall performance of the boiler.

New Boiler Replaces Old Boiler:

The information needed to evaluate the effectiveness of installing a new boiler at Sunnybrae Middle School to increase energy efficiency and save the school money depends mostly on three main costs associated with a new boiler. These three costs include the cost of installation, fuel and maintenance.

The current boiler is an older model that lacks efficiency and effective heat generation. Installing a new boiler which is more efficient and easier to control would not only save the school costs in fuel but provide a more comfortable classroom environment as well. Estimating the price of the new boiler, the costs associated with the installation of the new boiler and the cost of removing the current boiler are vital in determining if the costs of a new boiler meet the benefits a new boiler unit would provide. Unless there are unexpected leaks or damages to the pipes, most contractors will tie the new boiler into the existing infrastructure already in place.

The next cost associated with the effectiveness of a new boiler would be fuel. This cost is where the new boiler would be saving the school money.

Reduced fuel prices are critical in making the installation of a new boiler economically feasible. In the past years California has seen rapid spikes and declines in the price of natural gas. However, natural gas prices have had more up than down resulting in an overall increase in gas prices. Consequently, estimating fuel cost fluctuations will help to better approximate a return on investment. These prices could very well make or break the cost effectiveness of installing a new boiler.

The last cost associated with a new boiler system would be the maintenance of the system itself. To run at optimum efficiency boilers need constant maintenance and adjustments. So to calculate the effectiveness of the boiler an estimation of the costs associated with keeping the boiler running at a peak rate must be accounted for. With these cost taken into account the installation of a new boiler can be judged on it's effectiveness to not only provide the students with a more comfortable class setting but also save the school money in energy costs over a long period of time.

Forced-air heating:

For a forced-air system to be implemented in an effective way, a cost benefit analysis is required. Since forced-air systems have already been implemented in several buildings of the school district, including the newer part of Sunny Brea Middle School, most of the potential benefits and costs are already familiar to the school board. With this in mind, the bulk of the research would focus on comparing the latest models to the running costs and fuel efficiency of the existing ones. A second important part of this research would be geared towards the costs of maintenance and installation. This would also be done in order to be able to compare this alternative between. A third key part of this analysis would be the fuel efficiency to service provided ration. This is an important part of the research that would allow the school board to make a more informed decision, since both an affordable technology and a properly learning environment are their main interests.

Since the forced air systems would be installed in such a way that they are controlled by the teachers, the best use pattern must be part of this research, also that if they do use forced air systems, they can know how to use them in a way that enhances efficiency and reduces fuel consumption.

Co-Generation:

In order to implement a co-generation heating and electrical supply at Sunnybrae, a standard cost/benefit analysis must be conducted. This analysis would weigh potential cost savings and higher quality heat against the continuing inefficiency of the current boiler system. Provided co-generation offers a sufficient return on investment that would pay for the new facilities, implementation would presumably be feasible. Costs involved with the analysis include installation, maintenance, and fuel costs.

Installation would require the hiring of professionals who could properly size and install a co-generation facility. Criteria used for hiring could be based on cost, reputation and availability. It may be required that a new structure be built to house the new system – this could be contracted out locally or possibly carried out by current maintenance employees. Since natural gas already exists on site, no new fuel sources will be required.

In order to ensure peak efficiency, routine maintenance will be required. After appropriate training of current employees, including Mike Osborne, maintenance director, and Doug, custodial engineer at Sunnybrae, some routine maintenance will be carried out without additional staffing. Maintenance costs could include training seminars as well as additional paid hours required by both Mike and Doug, but the most significant maintenance costs will be associated with hiring engineers specific to cogeneration.

Fuel costs must also be determined in order to gauge any potential savings. California's sporadic fluctuations in natural gas prices make this difficult, but average-pricing increases will be used to approximate any fuel-cost savings.

Alternative Analysis:

The following is a detailed analysis of the feasibility of each alternative. Specific costs and fuel savings are addressed in light of our stated goal and objectives.

Structural Enhancements:

The simplest case scenario involves doing minor adjustments to the existing set up to maximize insulation in the rooms and better the use the present resources. In order to do this there are two categories of improvements that can be made: structural enhancements and boiler use modification. The structural enhancement involves working around the pre-existing structures to maximize insulation. This involves looking at drafts, pipes and windows. The boiler use modifications involve re-thinking the current use of the boiler. This involves times of use and temperature at which the boiler is run.

The current structures date from the 70's where much of the information and concerns that we now have were not in the main interest of constructors. The buildings are poorly insulated and the heat is lost at a very fast rate. The low temperatures of the classrooms, induces the boiler being run at a higher temperature. To improve the insulation of the class rooms the windows need to change to double-pane windows. Several window frames have cracks and are probably drafty. The doors have no proper seal and lead to an outdoor hallway, from where cold air sips in all night long.

Another modification in the classrooms that can be done by placing a plate or hood over the existing radiators would help disperse the heat vertically rather than horizontally, making the rooms more comfortable, and the heating more effective. Some of the teachers with rooms on the Complex have addressed this problem by placing large objects over the ventilation system. This aims to prevent the heat from rising and been lost through the un-insulated ceiling, but at the same time it reduces the effectiveness of the system by trapping the air.

The boiler itself could be run in a more efficient manner. If proper insulation is done, the rooms would not need so much initial heating, then the boiler can be set a lower temperature and make it run for longer periods of time. This would avoid the cold mornings and hot days that the students and teachers have to endure. This way of running the system would reduce fuel consumption on the long run as less BTU's are taken in and less heat is being lost.

To ensure that the right temperatures are being set, we recommend re-installing the thermostats that were once placed in the rooms. This will allow for a closer control and monitoring of the system that will in turn reduce the amount of heat excess and waste in the classrooms. It is important to make a note that all of the recommendation done above can be implemented to maximize the performance on any system that the school board decide on.

New Boiler:

One of the alternatives proposed to remedy the inefficiency of the current heating system at Sunnybrae Middle School is to replace the boiler with a new more efficient model. Mike Osborne director of maintenance for both Sunnybrae and Sunset schools estimated that the current boiler in question runs at an efficiency of only fifty percent. The installation of a new model boiler, typically rated at eighty percent efficiency or above would result in lower fuel use to keep the school heated and comfortable for both students and teachers. The use of less fuel would result in money saved due to less fuel costs.

With this in mind the costs associated with a new boiler alternative will most likely include the removal of the old boiler, the cost of a new boiler unit, the cost of a new burner and the installation of the new boiler.

Even though the infrastructure associated with the older boiler is old, most contractors will try to hook up the new boiler to the existing system to cut down on costs. The infrastructure associated with the current boiler is the burner, six floor standing radiators in six separate classrooms, the 660 ft. of pipes that deliver the heated water to the radiators and the vents that deliver the heat to the home economics and library areas. Replacement of this infrastructure if necessary is not easily estimated but is sure to cause the price of the project to go up considerably.

Replacement of the burner is necessary in the case that the current burner does not meet the current NOx standards put forth by the state. Being that the current boiler in Sunnybrae is over twenty-five years old the burner will most likely need to be replaced.

Presently the Rite Heating Boiler Engineering and Manufacturing Company's low-pressure boiler currently in use at the middle school is rated from the factory at taking in 760,000 BTU's while putting out 608,000 BTU's. When plugged into the equation [(Output BTU's/Input BTU's) X 100] the result is an efficiency rating of eighty percent. Although the unit is rated at eighty percent new Mike Osborne estimated the efficiency to be fifty percent due to degradation because of age. The new boiler's output should be equal to the current BTU rating. This will ensure that the heat provided to the classroom will at the very least be equal to the to what the current boiler system was putting out when new.

The new boiler should also be certified as an energy star certified product because efficiency in the heating system to save the school money is the primary goal of this project. A list of boiler manufacturers that have energy star certified products is listed in appendix 2 of this report.

The cost estimates of the installation of a new boiler are as follows. New boiler units rated at a BTU output in the area of 608,000 BTU's can cost in the range of $12,000 to $15,000[1]. The more efficient the boiler is the higher the price, but even at the base price the new boiler will have an efficiency rating of at least eighty percent. The removal and installation would be lumped together in one cost that could range from $8,000-$10,000[2]. This price range is assuming that no asbestos removal will be necessary in the removal or installation. When on site I did not see any asbestos in the boiler areas but asbestos can show in unlikely places in older buildings. If their was asbestos present the contractor would not be willing to deal with it and a separate hazardous waste crew would have to be called in to remove the asbestos. This would increase the amount of money that the project would cost considerably. Since the boiler room in the school allows for easy access the installation and removal cost would most likely be on the lower end of that scale. The cost of the replacement of the burner would be in the range of $5,000-$6,000[3].

Because the fuel use of the new boiler would be less than the old boiler the presumed fuel costs to the school would be lower as well. This is where the boiler would save the school money. Hopefully the savings in fuel costs would be higher than the price of the removal and installation of the new boiler. The current boiler runs between 7 Am to 11 AM Monday through Friday. Assuming the use of 760,000 BTU's per hour input this schedule results in the use of 3,040,000 Btu's per school day. On a monthly scale the current usage results in 63,840,000 BTU's being consumed per month. Using the current price of $0.71 per therm for commercial and school consumers and a conversion factor of

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[1] Baycity Boiler and Engineering Company
[2] Baycity Boiler and Engineering Company
[3] Baycity Boiler and Engineering Company

100,000 BTU's per therm the costs of running the current boiler comes to be $453.64 per month. Based on a nine-month school year the costs come to be $4079.38 school year.

With the newer more efficient boiler the projected fuel costs should be lower. Assuming that the current boiler is running at fifty percent efficiency replacing this boiler with a new one will raise the efficiency of the system by thirty percent. This should mean that thirty percent less natural gas would be used per month. This would mean that the new boiler would be consuming 191.5 less therms per month. At current prices this would equal a cost savings of $135.96 per month.

The current price per thousand cubic feet of natural gas in 2002 was $2.75 this price is expected to raise steadily to $3.70 per thousand cubic feet by 2020 and to $3.90 per thousand cubic feet by 2025 according to Report #: DOE/EIA-0383(2003) released by MIT in January of 2003 (Appendix 3).

This is a 41.8% increase over roughly a twenty-year period. Assuming that this increase follows a linear slope and that the price per therms increases at the same rate as the price per thousand cubic feet the price of a therm will be $1.01 per therm or a $0.30 increase by the year 2025.

The increase in price per therm over a twenty-year period can be broken down into an increase of $0.075 per five years. Breaking the price increase down to five-year increments reveals that by the year 2025 the school will have saved $36,972.15.

The third cost affecting the benefit of the new boiler is the maintenance costs associated with the boiler. This cost is speculative to judge since no one can tell what the boiler will need in the future. Sunnybrae already has two full time maintenance people that currently take care of the current boiler and other operations in the school. I am going to assume that no additional help will need too be hired to maintain the new boiler. Assuming the same maintenance would be needed to keep the new boiler running as the old one I estimate that there will be no change in the maintenance costs associated with a new boiler.

The total costs and savings contained within the replacement of the boiler are summarized in the two tables below.

Boiler Costs

New Boiler Cost	$12,000-$15,000
New Burner	$5,000-$6,000
Installation/Removal	$8,000-$10,000
Total Replacement Cost	$25,000-$31,000

Table 1

Boiler Savings

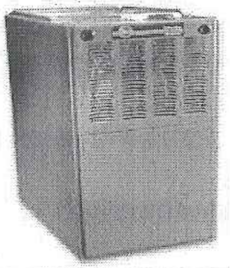
($135.98 per month) X (9 months) = $1,223.82 per year X 5 years = $6,119.10
($149.38 per month) X (9 months) = $1,344.42 per year X 5 years = $6,722.10
($164.71 per month) X (9 months) = $1,482.40 per year X 5 years = $7,411.95
($178.11 per month) X (9 months) = $1,602.99 per year X 5 years = $8,014.95
($193.43 per month) X (9 months) = $1,740.87 per year X 5 years = $8,704.35
Total Savings $36,972.15

Table 2

From the estimations and assumptions above, the replacement of a boiler that uses thirty percent would save the school anywhere from $11,972.15.30 to $5,972.15 including initial capital costs, over the course of a twenty year period.

The equations used to calculate the energy fuel savings are available in appendix 4. The alternative of buying a new boiler meets all the criteria set forth in our goals and objectives. Therefore it is our recommendation that the alternative of replacing the old boiler with a new more efficient one would be an appropriate alternative for Sunnybrae Middle School.

Forced Air Systems:



Forced-air is a method of heating, cooling and ventilating (HVAC). It is different than the current set up, because it uses a heat exchanger to warm the air instead of boiling several gallons of water to carry the heat to the air source. Forced air systems can be gas powered; the mechanisms can vary in size and set up which allows for flexibility around pre-constructed areas. This system is very effective at moving large quantities of air, and runs with an estimated efficiency of 80% or above. An advantage of this system is that it has already been installed in other schools of the district, as well as on several classrooms at Sunnybrae. Two rooms can share one small unit, thus increasing the control of the system according to the individual classroom needs. Also it has a good record of efficiency and comfort in the class according to some of the teacher that we talked to.

A forced air heating system uses gas burners for combustion; the combusted air passes through a heat exchanger and out a chimney flue. Cold air is drawn from the rooms then fan forced across the heat exchanger plates and into heating ducts that releases it back in to the rooms (Appendix 5). A thermostat records the temperature and can then stop/start the burners to regulate the temperature when it operates outside a pre-established range (Appendix 6). Several units are placed under the floor when crawl space is available. Since the school floor is slab, an external side unit or a ceiling unit can be placed. If a main unit is placed, it can run from the current boiler room. The costs related to set up include: the units, duct work for hot air and return system of cold air, set up and wiring of thermostat units, and placement of the flue. A fuel line must also be taken in account when several units are placed. To ensure quality heating flexible insulation-style ductwork is preferred. Maintenance costs include burner cleaning and periodical filter cleaning on the return ducts.

A forced air-heating unit can be small enough for a house or have a commercial capacity size. The smaller sizes can be used shared by several classes or a main commercial size one can be installed to replace the boiler. The costs of the units vary according to quantity, number of rooms per unit and the ductwork construction involved. A main commercial size forced air unit has the convenience of using the space of the boiler, it use the same ventilation and gas lines. Nevertheless, it involves the installation of several feet of ductwork to reach all the classrooms. In the complex building there is a ventilation duct already in place. These ducts can be cleaned and joined to provide for the return of the cold air. In the home economics rooms the ductwork would be less since it is next to the boiler room. In this case the library would require the most amount of ductwork that would need a lot of insulation. The best would be to have a separate small unit only for this building.

The cost savings from a forced air systems are based on the increased efficiency, the installation costs, and the price per unit installed, the maintenance and fuel costs. An increased in the efficiency of the heating system has a direct relation to the amount of money saved in fuel costs. The current system is estimated to be running at 50% efficiency. Since a new forced unit runs at 80% to 90% efficiency rate, the increase of 30% to 40% in the efficiency would lead to an equal reduction of the fuel consumption. Give that the school uses the boiler from 7 am to 11 am, five days a week at a rate of 760,000 BTU's per hour, the school is using 63,840,000 BTU's. As it was previously mentioned, this would account for a cost of $135.96 dollars per month. A 30% increase in efficiency would lead to a reduction on this fuel expense.

Another important aspects in of forced air systems is the consumption of fuel in terms of BTU's. New units have a BTU consumption of about 400, 000 BTU's per hour (Appendix 7). If the same running schedule is used for the new units, it would run for 4hour a day Monday through Friday. This would be 20hr/week and 80hr/month. This would add to 32,000,000 BTU's. If the cost per therm is of $0.71 and knowing that a therm is 100,000 BTU's, then the school will be spending an average of $227.20 dollars per month. If more than one unit is placed, we would need to multiply this fuel cost by the number of units.

The installation costs vary from set up to set up. The average cost would go around $40,000 to $55, 000 for 36,000 sq Feet with Arcata's weather pattern[4]. This would go up or down depending on the amount of units installed. An average residential forced air unit has a price range between $800 and $900 dollars. The estimated cost for thermostats is $60 dollars. An extra cost is the maintenance of the burners. To ensure a safe clean burning operation the burners must be inspected and cleaned once a year. This has a cost of $75 to $80 dollars, depending on the service provider. These routine inspections can also help detect drop on the overall performance of the system that would in turn lead to preventive small repairs instead of waiting for the system to deteriorate[5].

The ductwork is also a cost that must be factored. The average cost of a duct material is about $37.65 per room and a $75 cost for heat load calculations and minimal ductwork design. To this the insulation must be added. The insulation is one of the most important parts of the project as a problem with the ducts heat capacity can lead to a loss of 20% to 40% in efficiency, throwing away grate part of the savings made by replacing the boiler. This is especially true if external units are going to be placed around the building (Appendix 8).

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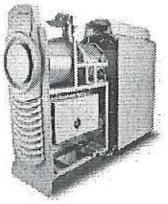
[4] Air Comfort Technologies

[5] Air Comfort Technologies



Co-Generation:

Introduction

Cogeneration, or "combined heat and power" (CHP), harnesses power and thermal energy from a single fuel source. Often "heat" and "electricity" are thought of as two separate lines of energy dependence, but cogeneration, as it has for over 100 years, is taking advantage of the fact that these two energy needs are not so different after all – in fact, they are practically one and the same. Often when we speak of the efficiency of an electrical generator, for example, "inefficiency" is inadvertently disregarded and assumed to be waste. Cogeneration, as previously suggested, is simply taking advantage of the fact that the resistance and exhaust of electrical generation can supplement home or business, *or a school's*, heating needs, even achieving 90% efficiency. This is referred to as a "topping cycle", in which exhaust gases or high-pressure steam are utilized for space or water heating *after* electricity production. The alternative type of cogeneration is a "bottoming cycle", in which electricity is produced from steam that has already been used for another process (Hinrichs 1996); this section will only focus on a topping cycle scheme for Sunnybrae.

Benefits:

Typical power plants waste up to 75% of their source fuel through heat loss, line transmission losses and other inefficiencies associated with centralized electrical energy production (www.cogeneration.net). In contrast, cogeneration can be an on-site production of both electrical and heating needs that is up to 90% efficient, making it ideal for energy reliability and cost savings, as well as conserving resources; Denmark, Finland and The Netherlands supply 30-40% of their energy with cogeneration (Kolanowski 2000) – but so as to not falsely color cogeneration, this alternative does still require a primary, off-site energy source, which in this case is natural gas. Yet the benefits extend beyond energy "independence": Cogeneration can save on money, energy and greenhouse gases, basically increasing economic efficiency while decreasing an ecological footprint. According to Michael Brown, Director of the World Alliance for Decentralized Energy (WADE), it is not only economically viable to the end user, but cogeneration also offers the most cost-effective method of carbon mitigation of any other technology at or near the market today (Brown 2003).

Drawbacks:

Elliot and Spur, authors of "*Combined Heat and Power: Capturing Wasted Energy*", identified barriers to a broader adoption of the cogeneration industry (Elliot and Spur 1998):

- a site-by-site environmental permitting system that is complex, costly, time consuming, and uncertain

- current regulations which do not recognize the overall energy efficiency of CHP or credit the emissions avoided from displaced grid electricity generation
- many utilities currently charging discriminatory backup rates and requiring prohibitive interconnection arrangements. Increasingly, utilities are charging (or are proposing to charge) prohibitive 'exit fees' as part of utility restructuring to customers who build CHP facilities
- depreciation schedules for CHP investments that vary depending on system ownership and may not reflect the true economic lives of the equipment
- a market which is unaware of technology developments that have expanded the potential for CHP.

Feasibility of Cogeneration at Sunnybrae:

The following is a feasibility study to find whether Sunnybrae is a good candidate for cogeneration; it will also be conducted in light of our stated goal and objectives.

System Sizing:

By using the data gathered from utility bills, part of finding whether or not Sunnybrae would benefit from cogeneration was a matter of matching this to a co-generator's electrical (kW) and thermal energy (btu) supply, multiplied by its time-of-use. This was essential because producing electricity that will be tied into the grid, in this case, is not 'paid for' by PGE, rather independent suppliers of grid energy can only produce a yearly average of what they consume(PGE 2003), thereby limiting cost-savings from electricity to 100% of the school's annual electric bill. Also part of a feasibility study is the issue of how much more/less natural gas will be used in the new cogeneration setup, and whether or not the captured heat from the cogenerator will be enough to fully supply or only supplement the school's heating demand. Since electrical demand determines the most influential cost-savings (Henrich 1999), we had to decide to either tie in to the old boiler system as a supplemental heat source or replace it altogether if enough usable heat remained from electrical generation. It was found that enough usable heat (50-55% of input) and enough (or at least not too much) electrical generation could be supplied with a 420,000 btu, 30kW cogeneration system (Kolanowski 2000).

Energy and Cost Savings:

According to Dr. Shawn Buckley, an employee of Cogen Power and Author of *Modular Low-Emission Cogeneration,* the average price for a microturbine (small-scale) cogeneration unit is about $1280/ kW (Buckley 2003). A 40kW cogeneration system would cost about $75,000, including installation. The natural gas consumed for this system is about 500,000btu/hr, or 5.0 therms/hr, and usable thermal energy equates to about 250,000btu/hr (Kalonowski 2000). Since overheating tended to be the issue with the old boiler, a 40kW cogeneration system that provides a little less heat (250,000btu usable vs. 350,000btu) is a feasible choice for room comfort (*further studies should be conducted to confirm replacement and not to supplement heat to the old boiler*).

Assuming that the generator runs a slightly longer schedule, 6am -2pm, Monday through Friday, excluding *most* of summer, the heat supplied should actually create a more comfortable environment, avoiding the overheating that tended to accompany the older boiler set-up. With this option of total replacement the total dollars saved each month on energy costs comes out to **$3684/mo,** with a payback period just over 20 years; *see figures below.*

- 40kW cogeneration system
    - 250,000 btu/hr usable heat
    - 8 hours of operation per day
    - kWh produced = 320kWh/day (80,000/yr)
        - 8hr/day x 40kW/hr x 5days/week x 250days/yr
    - Gas usage = 10,000 therms/year
        - 5therms/hr x 8hr/day x 250 days/year

Energy and Cost Savings:

	Cogeneration(40kW)	**Boiler**
btu input	500,000 btu	710000….
Efficiency(heat+electrical)	85%………………………	50%……..
gas savings($)	-284/yr	
electricity savings ($)	-8800/yr	
Maintenence	+5400/yr	
savings/yr ($)	3684	
Payback time	20.39 years	

This cost analysis does not take into account potential rebates. For cogeneration systems up to 1000 KW, the State of California will pay for 30% of the system cost including feasibility study, engineering, installation and the first three years of maintenance. The program expires in 2004 (cogeneration planners2000).

Greenhouse Gas Reduction:

Greenhouse gas reductions were figured by the total therms used under cogeneration versus the old boiler, each multiplied by its efficiency; the remaining difference of 'wasted' therms can then be converted to pounds of CO2, ppm NOx or CO, each being reduced by the percentage gain in efficiency; also taking into consideration the comparative amounts of natural gas (4% less) that is burned, and an increase in efficiency by almost 40%, the cogeneration unit will reduce greenhouse gases by about 40-45%.

Pros and Cons to Sunnybrae Cogeneration:

- Pros:
    - Increased efficiency ~ 40%
    - Decreased CO2 (GHG) ~ 40-45%
    - Saved $ on utility bills
    - Distributed generation conserves resources.
- Cons:
    - Payback over 20yrs
    - Heating needs inappropriate for cogeneration
    - On/Off doesn't work well with small units

- Many hidden costs

According to George Wright, Chief Engineer at HSU Plant Operations, units of the size appropriate to Sunnybrae have not had a dependable reputation if they are operated sporadically. Whereas some facilities require a 24-hour heat source (Arcata High's pool, possibly), the scheduled heating needs of Sunnybrae are not conducive to cogeneration (Wright 2003).

Conclusions:

After analyzing the potential costs and benefits of cogeneration, it was determined to be a poor option. The lack of needed run time and a lengthy payback makes the feasibility of cogeneration at Sunnybrae questionable. All things being considered, there are better technologies, or at least more appropriate technologies, which would better suit the needs at Sunnybrae.

Monitoring and Evaluation:

The monitoring and evaluation of a new heating system at Sunnybrae Middle School will be necessary to determine if the new system is beneficial to the school. The system will be evaluated on four objectives that we deemed necessary to accomplish if we are to consider a renovation of the current heating system successful. The first of these objectives is to create a system that is at least sixty percent efficient in its heat output. Secondly, we want to implement a heating strategy that will pay for itself in predicted energy savings over a ten-year period. Third, we want the system to provide a balanced range of temperatures to all the rooms in order to provide a comfortable learning environment. And finally, we would like to implement a system that will help Arcata meet its goal of reducing greenhouse gases by seven percent. With these criteria being monitored and evaluated we will be able to tell if the strategy we present to the school is advantageous to both the district and the students.

The efficiency of a system can be estimated from the input, output and technology of the equipment installed. Most of the new technologies have reports on the efficiency of the system. This information can also be found on manuals and catalogs, where makers specify the efficiency of the equipment. The current equipment has an efficiency of about 50%. If a boiler replacement was to be done, a monitoring on the improved efficiency should be done with the current efficiency as a base line and the new equipment performance report from the makers or providers. The same can be done if we look at replacement of the present boiler to a forced-air system. If a co-generation system is adopted, the efficiency can be measured in the same way. The electricity generated can be added as extra output or compared to the present cost of kilowatt/hour that this area is using based on appliances, fixtures and schedule of use. If only minor fixes on the room's insulation are done, then the efficiency can be focused more on the evaluation of the room's environment, more than the equipment input/output ratio.

In order for any new system to pay for itself in 20 years, that system's efficiency and estimated time of use will be compared to that of the old boiler, which was 50% efficient and would run an estimated 4-5 hours, five days a week.

By figuring out the total therms used for each new system, and by comparing the cost savings with estimated price fluctuations over ten years, either the money saved will add to at least the cost of the new system or else it does not meet this particular objective. In the case of cogeneration, kWh production will also be incorporated as cost savings and therefore influence payback time.

One of the main interests in addressing the boiler problem is the comfort of the students. Student and professors can fill in a report where they evaluate the performance of the heating system. This report can be done as often as needed and it should address the following: performance on warm days, performance on cold days, overall comfort in the classroom and conduciveness to learning. This type of survey can also have a comparative section that can be filled by continuing teachers and students who are old enough or remember how the old system used to work. In the case of not having a technology change, but more an increase on the room's insulation, this survey can be done more specific and valued more as part of the assessment and monitoring of the boilers performance.

Our final objective was to help Arcata meet its greenhouse gas reduction of 7%. Since each alternative will continue to be powered by natural gas, estimating CO2, a primary greenhouse gas stemming from the burning of natural gas, will involve figuring the total btu's that will be produced. This number will then be figured into pounds of CO2 released using the EPA's estimate of 7.89lbs/kBTU. Manufacturers will include BTU specs on their equipment and multiplied by time of operation this comparison and relative reduction will be a simple computation and comparison. If a new system decreases CO2 output by 7% this objective will be met. Also, cogeneration will involve a reduction on transported electricity, another waste area of energy use that increases the overall emission of CO2. This aspect, however, would require difficult estimates and therefore will not be part of our greenhouse gas reduction objective.

Monitoring and evaluating the heating plan that is implemented in the Sunnybrae Middle School will not only help the school evaluate the effectiveness of it's decision making but it will also allow other schools to learn from the success or the failures of the heating plan Sunnybrae adopts. Using this information, other schools can steer their future heating strategies towards a more efficient system based on the experience of others.

Recommendation:

After analyzing the costs and benefits of each alternative, we recommend that Sunnybrae Middle School implement a high-efficiency boiler along with modifications (radiator hoods, insulation upgrades in ceilings, thermostat replacement, etc.). After speaking with George Wright, he suggested that there are methods and technologies associated with boilers that can achieve up to 95% efficiency. Since much of the infrastructure for a boiler unit already exists, replacement costs can also be minimized.

Work Cited:

Brown, Michael. 2003. Jan/Feb - Volume 4 Number 1 - Carbon Finance and DE. Cogeneration and On-Site Power Production Magazine.

Buckley, Shawn, Dr. Online Paper. http://www.energy.ca.gov.

Elliott, R.Neal and Mark Spurr.1998.*Combined Heat and Power: Capturing Energy.*

"Forced Air Catalog"Salem Electronics. February 2003. <http://www.salemelectric.com/info/heating/forced_air.html>

Gilman, Kyle. Sales Represenative, Bay City Engineering. Personal Interview. April 22, 2003.

Energy and the Environment. New Allience. February 2003. <http://www.nwalliance.org/resources/reports/e98-004.pdf>

"Home Improvements and HVAC Systems." March 2003. < http://www.hometips.com/hyhw/comfort/43furnace.html>

"HVAC Systems for industrial and residential sights." March 2003. <http://www.ofenlochmechanical.com/HEATING.html>

Kolanowski, Bernard F. 2000. Small-Scale Cogeneration Handbook. The Faimount Press Inc. 2000.

MIT turbine energy flow. U.S. Environmental Protection Agency, 1998 Report #: DOE/EIA-0383(2003). January 9, 2003.

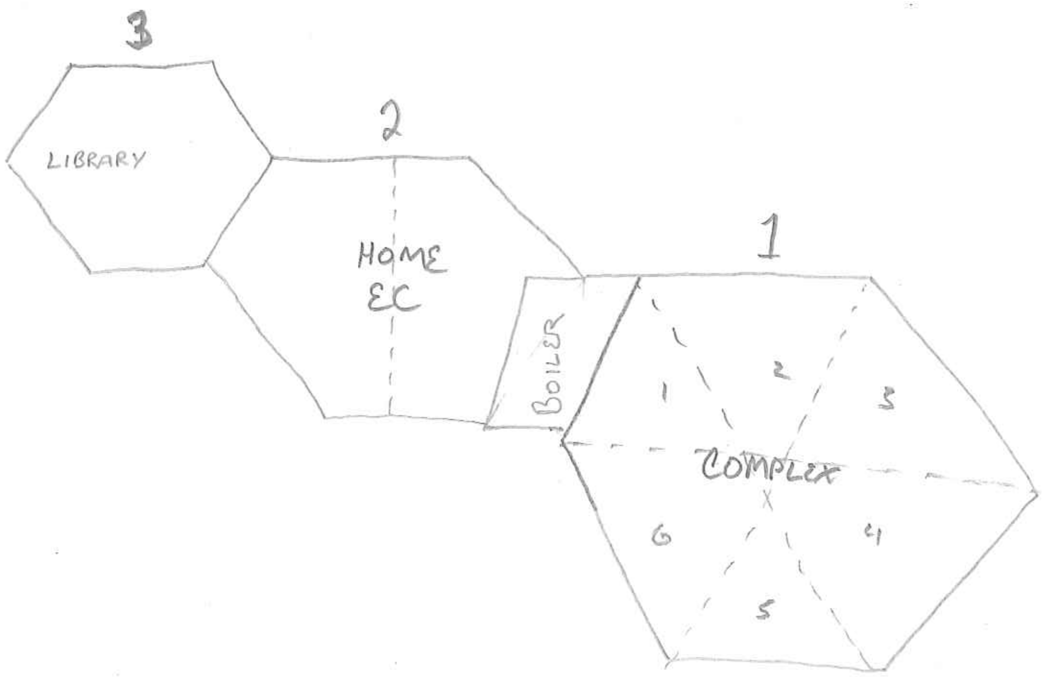
Wasted Energy. ACEEE Report-IE983.Washington, DC: American Council for an Energy-Efficient Economy.

Wright, George. Chief Engineer, HSU Plant Ops. Personal interview. May 5, 2003.

Appendix 1

Appendix 1: Site Sketch

SUNNY BRAE MIDDLE SCHOOL



Appendix 2

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Axeman-Anderson	(570) 326-9114
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Buderus Hydronic Systems	(603) 898-0505
Carrier Corporation (Bryant)	(317) 240-5205
Columbia Boiler Company	(610) 473-8457
Crown Boiler Company	(215) 535-8900
ECR, International - Dunkirk Radiator EXIT - Utica Boilers EXIT	(315) 797-1310 (716) 366-5500 (315) 797-1310
Energy Kinetics EXIT	(800) 323-2066
GlowCore	(330) 273-7770
Heat Transfer Products, Inc. EXIT	(800) 323-9651
Mestek, Inc. - Hydrotherm Boilers - Smith Boilers	(413) 564-5961 (413) 568-9571 (413) 562-9631
Monitor Products Inc. EXIT	(800) 524-1102 ext19
Peerless Heater Company	(610) 367-2153
Quincy Hydronic Technologies	(800) 501-7697
Quietside Corp.	(562) 463-0880
Slant/Fin Corporation	(516) 484-2600
Thermo-Dynamics Boiler Company	(570) 385-0731
Viessmann Manufacturing Company, Inc.	(401) 732-0667
Weil-McLain EXIT	(219) 879-6561

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ENERGY STAR® Labeled Boilers
Qualifying Product List
As of November 28, 2002

Manufacturer Name (Trade Name)	Product Family Name	Type (i.e., Steam or Water)	Fuel Type (eg. Gas, Oil, etc.)	AFUE Rating	CAafue Rating	Model Series
Axeman-Anderson Co.	Axeman-Anderson Boilers			85.3-88.1		Olympia I Series (including those used in the Centaurus hot water heating system and the outdoor heating module system) : Models OL-91, OL-119, GL-91
Axeman-Anderson Co.	Axeman-Anderson Boilers			86.0-86.1		PO-2 Series: Model 74POD-2, 87POD-2 (Damper, Light Oil)
Axeman-Anderson Co.	Axeman-Anderson Boilers			85.0-88.7		NPO Series: 74NPO, 87NPO, 108NPO, 128NPO; 74NPO-U, 87NPO-U, 108NPO-U, 128NPO-U
Axeman-Anderson Co.	Axeman-Anderson Boilers			85.1-86.7		Vesta Series: PVT models 105B, 119B, 119H-189H
Buderus Hydronic Systems	Gas Boilers	Water	Gas	85		G124x/DI/18, /25, /32
Buderus Hydronic Systems	Gas Boilers	Water	Gas	85.0-85.2		GA124/17, /23, 30
Buderus Hydronic Systems	Gas Boilers	Water	Oil	86.0-86.8		G115/21, /28, /34
Buderus Hydronic Systems	Gas Boilers	Water	Oil	86.0-86.3		G215/3, /4, /5, /6 models
Burnham	LE, LEDV Series	Water	Oil	87		LE-1, LEDV-1
Burnham	V8	Water/Steam	Oil	85-86.3		V83-7
Burnham	Revolution	Water	Gas	87-88		RV3, RV4, RV5, RV6, RV7
Bryant Heating & Cooling Systems	Plus Series Boilers	Water	Gas	90		All BW9 models (50,75,100)
Bryant Heating & Cooling Systems	BW4/BW5 Series Oil-Fired Boilers	Water	Oil	85.2 - 86.5		BW4/5 Series – Input sizes -91, -105, -126, -168
Carrier Corporation	WeatherMaker® Boilers	Water	Gas	90		All BW9 models (50,75,100)
Carrier Corporation	BW4/BW5 Series Oil-Fired Boilers	Water	Oil	85.2 - 86.5		BW4/5 Series – Input sizes -91, -105, -126, -168
Columbia Boiler	LV and LVD Series	Water		85.2		LV 75, LVD 75, LV 125
Columbia Boiler	WB Series	Water		85		WB 125
Columbia Boiler	Solaia Series	Water		85.5		SL375
Columbia Boiler	Solaia Series	Water		86.5		SL4100
Columbia Boiler	Solaia Series	Water		86.9		SL5125
Columbia Boiler	Solaia Series	Water		86.9		SL6150
Crown Boiler Co.	Tobago	Water	Oil	85.8-86.1		TW2-065, TW2-075, TW2-090, TW2-120
Crown Boiler Co.	Freeport	Water	Oil	86.1-87.6		CT-3, CT-4, CT-5, CT-6, CT-7
Dunkirk Radiator Corp.	Quantum Leap (QL) Series	Water		95		QL-50, -75, -100
Dunkirk Radiator Corp.	EV Series	Water		87.4-87.6		Models DPFO-3-9/3T-8T, and models ending in UDES or DES
Dunkirk Radiator Corp.	Empire Series			85.1-86.4		Models 3E.60, 3E.75, 3E.75C, 4E.90, 4E1.25, 4E1.25C, 4E1.50, 4E1.50C, 5E1.20, 5E1.20C
Dunkirk Radiator Corp.	Empire Series	Water		86.3		3EW.65T, 4EW.90T, 5EW1.20T
Dunkirk Radiator Corp.	Quantum-90	Water		90		Q-90-50, -75, 100
Dunkirk Radiator Corp.	Ultimate Products			87.4-87.6		All models beginning with PFO-3-9-/PFO-3T-8T and all models ending with UDES

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As of November 28, 2002

Manufacturer Name (Trade Name)	Product Family Name	Type (i.e., Steam or Water)	Fuel Type (eg. Gas, Oil, etc.)	AFUE Rating	CAafue Rating	Model Series
Energy Kinetics	System 2000	Water	Oil	86.2-87.5		EK-1, EK-1-DV, EK-2, EK-2-DV
Energy Kinetics	System 2000	Water	Gas	85-86		EK-1, EK-1-DV, EK-2, EK-2-DV
Energy Kinetics	System 2000	Water	Propane	86-88		EK-1, EK-1-DV, EK-2, EK-2-DV
Glowcore	Water Boiler	Water	Gas	92		GBA1
Heat Transfer Products, Inc.	Gas Fired Condensing Boiler			92		Munchkin 80M
Heat Transfer Products, Inc.	Gas Fired Condensing Boiler			92		Munchkin 140M
Heat Transfer Products, Inc.	Gas Fired Condensing Boiler			92		Munchkin 199M
Hydrotherm Boilers	Pulse			90.3-90.6		AM-100, AM-150, AM-300
Hydrotherm Boilers	Sabre Series			86.0-86.5		FX-70, FX-105, FX-140, FX-175, FX-200
Monitor Products, Inc.	MZ-Wall Hung Condensing Boiler	Water	Gas	95		MZ 40C, MZ 25S, MZ 25C
Monitor Products, Inc.	Fully Condensing Boilers	Water	Oil	92-97		FCX fully condensing boiler
Peerless®	Gas Fired Boiler	Water	Gas	85.0		Series PDE-03, Series PDE-04, Series PDE-05
Peerless®	Gas Fired Boiler	Water	Gas	92.0		Pinnacle™ - PI-80, PI-140, PI-199
Peerless®	Oil Fired Boiler	Water	Oil	86.1		Series WBV-03-.60 gph
Peerless®	Oil Fired Boiler	Water	Oil	86.1		Series WBV-04-.95 gph
Peerless®	Oil Fired Boiler	Water	Oil	86.6		Series EC/ECT-03- .75 gph
Peerless®	Oil Fired Boiler	Water	Oil	85.3		Series EC/ECT-03- 1.00 gph
Peerless®	Oil Fired Boiler	Water	Oil	86.1		Series EC/ECT-04- 1.25 gph
Peerless®	Oil Fired Boiler	Water	Oil	85.2		Series EC/ECT-04- 1.50 gph
Peerless®	Oil Fired Boiler	Water	Oil	86.2		Series EC/ECT-05- 1.75 gph
Peerless®	Oil Fired Boiler	Water	Oil	85.2		Series EC/ECT-05- 2.00 gph
Peerless®	Oil Fired Boiler	Steam	Oil	85.4		Series EC/ECT-03- .75 gph
Peerless®	Oil Fired Boiler	Steam	Oil	85.1		Series EC/ECT-04- 1.25 gph
Peerless®	Oil Fired Boiler	Steam	Oil	85.6		Series EC/ECT-05- 1.75 gph
Peerless®	Oil Fired Boiler	Water	Oil	86.7		Series WV-DV-03 WPC-.75gph
Peerless®	Oil Fired Boiler	Water	Oil	86.7		Series WV-DV-03 WPCT-.75gph
Peerless®	Oil Fired Boiler	Water	Oil	85.9		Series WV-DV-03-WPC-.85gph
Peerless®	Oil Fired Boiler	Water	Oil	85.9		Series WV-DV-03-WPCT-.85gph
Quietside	QVM-9	Water	Gas	90		QVM9-090/125/150
Quietside	QVM8-OL	Water	Oil	85		QVM8-085/120/150 OL
Slant/Fin Corporation	Prodigy 21 Boilers			86		KCS-50, KCS-100
Slant/Fin Corporation	Liberty			86		L-30H, L-40H, L-50H
Slant/Fin Corporation	Concept 21			85-85.6		CB-45, CB-90, CB-135, CB-180
Slant/Fin Corporation	XL-2000			83.56-85.05		XL-20, XL-30, XL-40, XL-50
Smith Cast Iron Boilers	8 Series			85.1-86.2		8W/S3 - 8W/S6, 8W/S3T - 8W/S-6T
Smith Cast Iron Boilers	Lexington Series			86.0-86.5		GS110-3 through GS110-7

ENERGY STAR® Labeled Boilers
Qualifying Product List
As of November 28, 2002

Manufacturer Name (Trade Name)	Product Family Name	Type (i.e., Steam or Water)	Fuel Type (eg. Gas, Oil, etc.)	AFUE Rating	CAafue Rating	Model Series
Thermo-Dynamics Boiler Company	LM Series	Water		85.2		LM-75 and LM-125
Thermo-Dynamics Boiler Company	LMD Series	Water		85		LMD-75
Thermo-Dynamics Boiler Company	CWL Series	Water		85		CWL-85, CWL-85 DV
Thermo-Dynamics Boiler Company	HT Series	Water		85.6		HT-175
Thermo-Dynamics Boiler Company	HT Series	Water		86		HT-165
Thermo-Dynamics Boiler Company	HT Series	Water		85		HT-125
Thermo-Dynamics Boiler Company	LV and LVD Series	Water		85.2 - 85.0		LV 75, LVD 75, LV 125
Thermo-Dynamics Boiler Company	WB Series	Water		85		WB 125
Utica Boilers	Star Fire III			86		SFH 365, 4100, 5125, 6150
Utica Boilers	STAR Fire II & SW Series	Water		86		SFH - 365W, 4100W, 5125W, 6150W
Utica Boilers	BC-Series			86		BC-3D, BC-4D
Utica Boilers	USC-Series	Water		87		USC-3, USC-4, USC-5
Utica Boilers	Ultimate Series	Water		87.5		PFO - 3, 4, 5, 7, 9
Utica Boilers	CSFH111	Water		86		CSFH 365, 4100, 5125, 6150
Utica Boilers	CSC	Water		87		CSC- 3, 4, 5
Viessmann	Vitogas 100	Water	Gas	85.4 - 85.6		GS1-22 through GS1-60
Viessmann	Vitorond 200	Water	Oil	86.7 - 86.9		VR2-18 through VR2-63
Viessmann	Vitola 200	Water	Oil	87.1 - 87.4		VB2-18 through VB2-63
Viessmann	Vitodens 200	Water	Oil	94.0 - 94.2		WB26-24 through WB215-60
Weil-McLain	Gold Oil Boilers	Water	Oil	85.0-85.9		Model WGO-2 through GO-7, WTGO-3 through WTGO-7
Weil-McLain	Gold Gas Boilers	Water	Gas	87.0-87.5		Model GV 3-6
Weil-McLain	Wall-Mounted High-Efficiency Gas Boilers	Water	Gas	85.3-85.5		Model AHE-45 and AHE-60

Appendix 3

Average natural gas prices (including spot purchases and contracts) are projected to drop from $4.12 per thousand cubic feet in 2001 to $2.75 per thousand cubic feet in 2002. After 2002, natural gas prices are projected to move higher as technology improvements prove inadequate to offset the impacts of resource depletion and increased demand. Natural gas prices are projected to increase in an uneven fashion as higher prices allow the introduction of major new, large-volume natural gas projects that temporarily depress prices when initially brought on line. Prices are projected to reach about $3.70 per thousand cubic feet by 2020 and $3.90 per thousand cubic feet by 2025 (equivalent to more than $7.00 per thousand cubic feet in nominal dollars).

Report #: DOE/EIA-0383(2003)

Released: January 9, 2003

(Next Release: January 2004)

Appendix 4

Daily BTU use:
(760,000 BTU's per hour) X (4 hours per day) = 3,040,000 BTU's per school day

Weekly BTU use:
(3,040,000 BTU's per day) X (5 days per week) = 15,200,000 BTU's per week

Monthly BTU use:
(15,200,000 BTU's per week) X (4.2 weeks per month) = 63,840,000 BTU's per month

Therms used per month:
(63,840,000 BTU's per month)/(100,000 BTU's per therm) = 638.4 therms per month

Cost per month
(638.4 therms per month) X ($0.71 per therm) = $453.26 per month

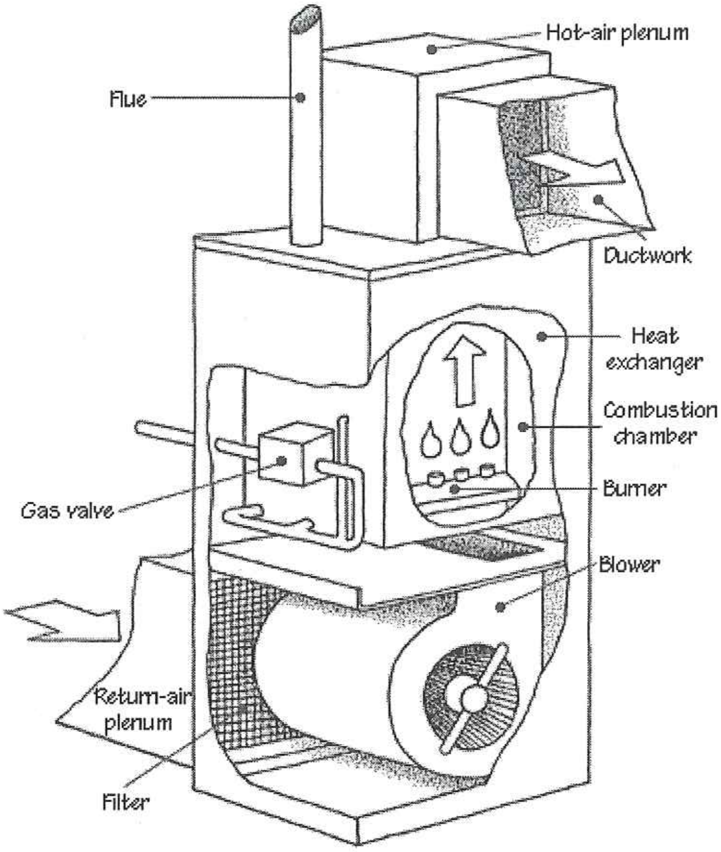
Cost per year:
($453.26 per month) X (9 months per year) = $4,079.38 per year

Therms Saved
(638.4 therms) X .3 = 191.52 therms saved

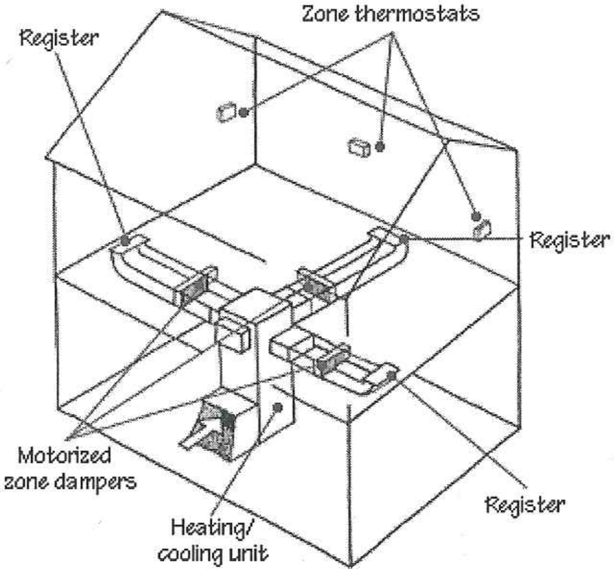
Price of therms saved per month:
(191.52 therms) X ($0.71 per therm) = $135.98
(191.52 therms) X ($0.78 per therm) = $149.38
(191.52 therms) X ($0.86 per therm) = $164.71
(191.52 therms) X ($0.93per therm) = $178.11
(191.52 therms) X ($1.01 per therm) = $193.43

Cost savings per year:
($135.98 per month) X (9 months) = $1,223.82 per year X 5 years = $6,119.10
($149.38 per month) X (9 months) = $1,344.42 per year X 5 years = $6,722.10
($164.71 per month) X (9 months) = $1,482.40 per year X 5 years = $7,411.95
($178.11 per month) X (9 months) = $1,602.99 per year X 5 years = $8,014.95
($193.43 per month) X (9 months) = $1,740.87 per year X 5 years = $8,704.35
Total Savings $36,972.15

Appendix 5


Hot-air plenum
Flue
Ductwork
Heat exchanger
Combustion chamber
Burner
Gas valve
Blower
Return-air plenum
Filter

Appendix 6


Zone thermostats
Register
Register
Motorized
zone dampers
Heating/
cooling unit
Register

1- MIKE
2- GREGG
3- MAJE

INDIVIDUAL / GROUP SCHEDULE COMBINED

Appendix 7

	TIME	DAY	ATTENDEES	ACCOMPLISHMENTS
(:30)	4-4^{30} PM	1/29/03	1,2,3	PROBLEM INTRO / BRAINSTORMING
(1:00)	2^{30} - 3^{30}	2/03/03	1,2,3	MADE CONTACTS W/BLOOMFIELD, SET GROUP GOALS, ALLOCATED RESPONSIBILITIES BRAINSTORMED "WHY AN ENERGY AUDIT?"
(:50)	2:40/3:30	2/05/03	1,2,3	ORGANIZED NEXT WEEKS LAYOUT... CONTACTS / QUESTIONARE
(1:00)	2:00/3:00	2/10/03	1,2,3	GENERAL WRITEUP DISCUSSION
(1:00)	2:00/3:00	2/12/03	1,2,3	AUDIT FORMAT BRIEF
(1:00)	11:00/12:00	2/15/03	1,3	TRIP TO BLOOMFIELD
(1:00)	2:00/3:00	2/17/03	1,2,3	PROBLEM STATEMENT
(2:30)	2:00/4:30	2/19/03	1,2,3	PROBLEM STATEMENT
(1:00)	2:00/3:00	2/24/03	1,2,3	PROBLEM STATEMENT / HISTORY
(2:00)	2:00/400	2/26/03	1,2,3	PROB STATEMENT
(1:00)	2:00/3:00	3/3/03	1,2,3	" " FINAL TOUCHES
(2:30)	2:00/4:30	3/5/03	1,2,3	GOALS / OBJECTIVES
(1:00)	2:00/3:00	3/10/03	1,2,3	" "
(1:00)	200/300	3/12/03	1,2,3	
—	—	3/17		
(1:30)	2:00/330	3/19	1,2,3	
(1:00)	200/300	3/24	1,2,3	
(1:00)	200/300	3/26	1,2,3	WEIGHING ALTERNATIVES
(1:00)	200/300	3/31	1,2,3	WEIGHING " "
(1:00)	200/300	4/7	1,2,3	IMPLEMENTATION
(1:00)	200/300	4/9	1,2,3	IMPLEMENTATION
		4/16	1,2,3	
(1:00)	200/300	4/21	1,2,3	MONITORING EVALUATION
(2:00)	200/400	4/23	1,2,3	EDITING
(2:00)	2/400	4/28	1,2,3	EDITING (PRESENTATION)
(5:00)	12/500	5/6	1,2,3	EDITING (PRESENTATION)
(3:00)	2/500	5/8	1,2,3	EDITING (FINAL DRAFT)

Apendix 8

Review of Literature 1989-1997
Impacts of Forced Air Distribution Systems on Homes and Potential for Improvement

A. B. Boe
OSU Extension Energy Program

Background and Summary of Findings

This literature review is part of a duct efficiency pilot program co-sponsored by the Northwest Energy Efficiency Alliance [NEEA] and the Electric Power Research Institute [EPRI]. A literature search was conducted by Washington State University Cooperative Extension Service Energy Library. In addition to articles identified by the library, project staff in Oregon and Washington contributed a number of articles from their own collections. In all, approximately 107 articles or studies dating from 1989 to the present were collected and reviewed.

Duct literature supports several broad conclusions:

1) Deficiencies associated with forced air distribution systems cause large energy losses and can have other unintended effects on people and buildings. Reported energy losses range from 10-40% with 30-40% being typical. Other unintended effects include health, safety, air quality and building life issues.
2) Duct losses are influenced by housing characteristics and duct location within homes. Homes with a large percentage of ducts inside conditioned space—such as homes or multifamily buildings with conditioned basements, or new manufactured homes—experience losses at the lower end of the range: 10-20%. Homes with large portions of their ductwork outside heated space—homes built on crawlspaces--experience higher losses: 20-40%.
3) When distribution system components are accessible, various repairs/improvements can be cost effectively performed.

To place the energy losses from forced air distribution systems in perspective, annual efficiency losses in the range of 30% are of comparable magnitude to the total energy savings from all of the building envelope measures in Northwest utility sponsored energy efficient home programs [Palmiter, Francisco, 1994]. Regional housing programs focused on aggressive improvements to the building envelope such as increased insulation, thermally improved windows and doors, attention to air tightening and ventilation. In the absence of technical knowledge of duct system effects, ducts were under-appreciated and duct improvements under-emphasized.

Studies of duct system effects and repair benefits have been conducted in a range of housing types. Earlier studies focused on duct system impacts in site-built single family homes. Later studies broadened this focus to include duct impacts in manufactured homes, multi-family homes and small commercial buildings. We now have a better idea about comparative distribution system impacts in homes with ducts outside conditioned space [ducts in attics and crawlspaces] and homes with ducts inside conditioned space [typically homes with basements].

Studies have been conducted by researchers at federal laboratories and by private engineering consultants across the US. Duct systems in Minnesota, New York, Wisconsin, North Carolina, Tennessee, Florida, Arkansas, Arizona, California, Oregon, Idaho, Montana and Washington have been tested and are reported in the literature. In addition to the published record of such activities, duct improvement projects have been or are being carried out in many other states as well. Studies include homes utilizing electricity as well as natural gas for space conditioning. Distribution system effects in cooling climates as well as heating climates are documented.

Costs and energy savings benefits of duct improvements in existing homes have been extensively reported. Reports of duct improvement costs in new construction are relatively rare. In retrofit situations, reported costs have ranged from $200-$500 per home. It is presumed, but not clear from cost reports, that costs of performance testing by the repair technician have been included in these figures. One Northwest study that included average new construction costs placed duct sealing improvements at $301/home, and tracked other additional associated costs such as load calculations $75, and distributed returns and /or pressure relief $403. [Haskell 1995]

Studies report average decreases in annual energy use for homeowners in the range of 10-20% due to duct improvements. Where studies have examined costs of the energy savings to the utility, levelized costs have been in the range of 10-30 mills per kWh. Recent studies on large samples of Oregon and Washington homes report levelized costs of 13-17 mills/kWh. [Robison et. al 1997; Lerman 1997]

In addition, since space heating or cooling system run-times are greatest when outdoor temperatures place their heaviest demand on regional utility networks, several studies document reductions in peak demand to the utility system as well as annual energy savings to the homeowner. [Cummings, Tooley & Moyer 1991; Proctor 1991; Modera et. al. 1992; Vigil, Cummings, Moyer 1993; Horowitz, McGraw & Anderson 1994; Kolb & Ternes 1995]

About a third of the literature reviewed presents field procedures for implementing duct improvements or addresses associated technical issues of interest to people actually doing repair work. Technical literature of this sort includes testing and repair protocols, technical manuals and a range of other information about rapidly developing technologies and techniques. Technical literature attempts to fill a need for training that is universally recognized as a critical component in all serious attempts to implement wide-scale improvements to forced air distribution systems. It is important to note that most of the diagnostic techniques that help make duct repairs cost effective and safe are under 10 years old and, except in areas benefiting from aggressive utility sponsored duct programs, are virtually unknown to the mainstream hvac [heating, ventilating, air conditioning] industry. Because early efforts at duct repair adapted tests and equipment used for building envelope analysis, in many areas people doing building analysis in the weatherization/conservation community currently have more experience doing duct diagnostics and repairs than hvac technicians responsible for original duct installation.

As ducts received increasing attention, new equipment and testing techniques were rapidly introduced. In 1993, equipment for directly measuring air leakage in duct systems became readily available for the first time. Before that, neither the hvac industry nor the conservation community had the means to quickly evaluate air tightness of ducts. Once new equipment was placed in use, measurements showed air leakage to be much more extensive than anyone had previously imagined. Although conductive losses through ducts had been recognized as a contributor to space conditioning loads, the magnitude of losses due to duct air leakage were an unpleasant surprise. By late 1997, equipment that seals ducts "from the inside out" using a liquid sealant vapor [aerosol based duct sealing] was commercially available [Modera, Dickerhoff et. al.1996]. Although some national hvac professional associations are showing interest in duct improvements, most hvac professionals are not aware that this technology exists. Without broader recognition within the hvac industry of duct system diagnostic and repair techniques, energy savings and other benefits of duct repair efforts will not be achieved on a wide scale.

Although we have learned a great deal about ducts in the past 10 years, there are still gaps in our knowledge. For instance, a specific study of the prevalence of forced air systems in Northwest housing has yet to be undertaken, although it is known that a significant number of Northwest homes have forced air distribution systems. A 1993-1995 survey of builders participating in regional site-built energy efficient home programs,[Lubliner et. al., 1995] found that for 68% of builders, the most common hvac system is a forced air ducted system. Over two thirds homes built by these builders were found to be non-basement homes with ducts outside heated space. 61% of the builders install ducts and air handlers in unheated crawlspaces, attics and garages. While this estimate of forced air systems is helpful, it is biased towards builders in electric utility programs and may not account for Northwest homes built using natural gas forced air systems.

Measurements of heating system efficiency have been conducted in existing site-built and manufactured housing. But no comparable efficiency measurements have occurred on systems that were aggressively sealed and performance tested during initial installation. Consequently we do not currently know the upper limit of duct efficiency improvements in new construction. Only 1 study has currently been conducted to assess energy penalties /repair benefits associated with duct system leakage and system efficiency losses in commercial buildings. [Withers et.al. 1996]

On a national level, discussions continue about standardized methods for determining system efficiency based on field measurements or general system design information [Andrews 1996].

In spite of a decade of increasing attention to ducts, the industry involved in fabricating and installing ducted systems is largely uninformed about duct performance issues, as is virtually every other segment of the construction industry: homebuilders, Realtors, lenders, utilities, and home buyers. Major opportunities are being lost that could make our housing more comfortable, more affordable to operate, safer, healthier, and longer lasting.

Effects of Forced Air Distribution Systems on Homes

Higher Energy Use

During the 1985-86 heating season, 510 NW homes built in 1984 were metered to determine space heating energy use. This early large sample study provided important information about the energy implications of heating system choices and helped to stimulate much subsequent distribution system research. The sample included 220 new homes built to NW Model Conservation Standards [MCS] in the Residential Standards Demonstration Program sponsored by Bonneville Power Administration and regional electric utilities. In addition to the MCS homes, energy use was metered in 290 "control group" homes built according to typical current practice. Results of monitoring were analyzed in two 1989 studies. Both studies concluded that, homes with electric forced air furnace systems used more energy for space heating than homes with zonal electric systems. [Lambert & Robison 1989; and Parker 1989]

Control group homes with electric forced air systems used 22% more energy than control homes with zonal heat. MCS homes with forced air systems used 13% more space heat energy than MCS homes with zonal heat. [Parker 1989].

Blower door testing showed homes with electric forced air furnace systems were also leakier—had more building leakage area [ELA]--than homes with zonal systems. Control group forced air homes were 26% leakier than control group homes with zonal systems. MCS group forced air homes were 22% leakier than MCS homes with zonal systems. Measurements of leakiness using tracer gas methodology indicated that the average annual air infiltration rate in forced air homes was approximately 70% greater than in non-forced air homes. Air infiltration can have a large effect on space heating energy use, but the increased leakage area alone did not seem to account for the difference in space heat use.

Space Heat Energy Use by Heating System Type in Pacific NW Houses [Parker 1989]

Heating System Type	MCS kWh/ft2	Control kWh/ft2
Baseboard electric	3.19	5.28
Forced air electric	3.65	6.68
Heat pump	3.52	3.37

From a consumer perspective, the heating systems that were the most expensive to install were also the least efficient. Why was this happening? Subsequent research began to answer that question.

Mark Modera, a researcher at Lawrence Berkeley National Laboratory, describes 4 "deficiencies" of forced air distribution systems: 1) conductive heat transfer across duct system walls; 2) direct air leakage to and from ducts; 3) increases in uncontrolled air flow through building envelope leaks due to air flow imbalances and pressure imbalances caused by duct leakage and other aspects of distribution system design; and 4) a "thermal siphon effect" or "thermal bridging effect" that causes a portion of space conditioning energy to be drawn out of the home while the forced air system is off. [Modera 1989 and Modera & Jansky 1992]

Conduction: Heat Loss [or Gain] Through Duct Walls

The hvac industry and conservation community have long recognized the potential for conductive heat loss or gain through duct walls. Conduction occurs when the temperature of the duct is different from the temperature of the surrounding attic, basement or crawlspace. In cooling climates, when ducts pass through hot summer attics, conductive heat gain through duct walls significantly diminishes the ability of cooling equipment to maintain comfort inside the home. In heating climates, the reverse occurs: during heating season, ducts experience significant conductive heat losses to the surrounding unheated or partially heated zones. Conductive losses alone are estimated to reduce system output by 20-25%.[Andrews & Modera, 1992]

Conductive losses are generally addressed by increasing duct insulation. In many parts of the US, ducts are uninsulated or only minimally insulated [R-2-R-4]. Poorly insulated ducts are common in the Northwest, too, but weatherization specifications and many Northwest energy codes currently require R-8 duct insulation. Many estimates of losses due to conduction assume uninsulated or marginally insulated ducts as a baseline. Conductive losses may not be as serious when R-8 insulation is already in place [Palmiter & Francisco 1997]. However, it is safe to say that in general, the most highly conditioned air in homes –the air in the duct system—is the most poorly protected from conductive losses. In the Northwest, we protect buildings that contain 70 degree air with R-21 wall, R-30 floor and R-38-49 ceiling insulation; while we protect ducts containing 90-140 degree air with R2-R8 insulation.

Another strategy to improve system efficiency by reducing conductive losses is to keep duct runs inside conditioned space. If ducts are inside conditioned space, any losses they incur ultimately help meet building heating or cooling loads. Applying the same strategy to existing homes, conductive and other duct losses can sometimes be addressed by improving the building envelope around the duct rather than repairing the duct itself. This is called "bringing the ducts inside the building thermal and air pressure boundary" so that losses can contribute to indoor comfort, rather than detract from it.

How Ducts Affect Uncontrolled Air Flow

Operation of forced air systems was found to increase uncontrolled air flow in buildings in three ways: leakage directly to and from ducts; leakage through other openings in the building envelope due to air flow and pressure imbalances caused by duct leakage; and a thermal siphon effect when the system is off.

Researchers in Florida, Jim Cummings and John Tooley, have characterized forced air system operation as one of the largest driving forces of uncontrolled air flow in homes. Many other studies have supported their findings, reporting drastic increases [200-300%] in uncontrolled air flow when forced air systems operate. [Cummings & Tooley 1989]

1) Leakage directly to and from ducts.

When the air handler fan operates, ducts on the return side of the system are strongly depressurized, or negative with reference to surrounding air pressure, so leaks on the return side of the system bring unconditioned air into the return system from the area surrounding the duct. Ducts on the supply side of the system are strongly pressurized, or positive with reference to surrounding air pressure, so leaks on the supply side of the system lose highly conditioned air to the surrounding area.

Even though duct leaks typically account for only 10-20% of total building leakage area, because duct leaks are exposed to the furnace air handler fan or "blower," duct leaks are exposed to much higher forces [pressure differences] than leaks in the rest of the building. In 5 Florida homes that received extensive testing, infiltration caused by forced air system operation was 7 times greater than natural infiltration [Cummings and Tooley 1989].

Mark Modera of Lawrence Berkeley Laboratory drew the same conclusion: infiltration and ventilation impacts of duct system leakage are significantly larger than those for building envelope leaks because of the large pressure differentials driving flow through duct leaks. Measurements indicated that pressures across duct leaks—created by the air handler fan or "blower"--could be 10 times higher than pressures across holes in the building envelope caused by natural forces [Modera 1989].

2) Increased leakage through building envelope leaks, caused by forced air system operation.

Because of duct leakage, forced air system operation exposes the home to flow imbalances and pressure differences that –over and above direct losses through the ducts—is a strong driving force for leakage through the building envelope. This was "discovered" by Florida researchers [Tooley and Moyer,1989] when they measured pressures inside homes while forced air systems operated. If a system experiences return side leakage, large amounts of air will be sucked into the return system , will flow through the air handler and be delivered to the home as additional air. As return leakage is delivered to the home, home air pressure increases [home becomes pressurized] with respect to outside air pressure and air will flow from the home[high pressure] to the outside [lower pressure] through holes in the building envelope. If a system experiences supply leakage, large amounts of conditioned house air will be lost to the crawlspace. When this occurs, air pressure inside the home decreases [home becomes depressurized]with reference to outside air pressure and outside air [higher pressure] flows into the home [lower pressure] through holes in the building envelope. In general terms, the duct system is "interacting with the building envelope," increasing pressures that drive uncontrolled air flow across building leaks.

In a tightly sealed forced air distribution system, the amount of air flowing out of the home through the return grilles will be equal to the amount of air flow into the home through the supply registers. Therefore, system operation will not result in unbalanced flows or create the kind of unbalanced pressures that so strongly increase building envelope leakage. The same balance may be coincidentally attained when the return and supply leaks just happen to be equal. However, if either return or supply leaks are dominant, flow imbalance occurs, and pressures created by flow imbalance force rapid leakage through building envelope leaks.

In fact, researchers discovered , another circumstance causing increased building envelope leakage: interior door closure. When forced air systems are designed with only one or two central return grilles, closing interior doors causes return/supply flow imbalance. When doors are closed, supply air delivered to bedrooms can't flow back to return grilles in the hall. Bedrooms become pressurized [air is entering through supply registers faster than it can leave] and return zones become depressurized [air is leaving through the return grilles faster than it can be replaced]. The pressure imbalances caused by door closure result in increased leakage through holes in the building envelope. This effect does not occur when systems are designed with multiple, distributed return grilles. [Tooley & Moyer 1989].

Energy Penalties Associated with Forced Air Distribution Systems.

Annual Space Heating or Cooling Penalties

Most assessments of energy penalties are based on short term monitoring—usually several days to several weeks. In other cases, long term monitoring is used. In short term monitoring studies, energy use is measured with power meters and recorded by data loggers. Weather data is collected. Energy use is correlated to outdoor temperature. Energy use software is used to extrapolate short term results to the entire year using Typical Meteorological Year [TMY] weather data. In other studies field measurements are used to develop a "prototype home" whose energy use patterns over the year are simulated using software and observed . In other cases prototypes are used to assess effects of various repair strategies.

Based on short term studies prior to 1992, John Andrews, Brookhaven National Laboratory ,and Mark Modera, Lawrence Berkeley National Laboratory [Andrews & Modera 1992] estimated that the energy penalty due to direct duct leakage was approximately 7.5% of total system output, and that system impacts on building envelope air flow equaled about 9% of system output, for a combined effect of approximately 15-20% of output. Conduction losses were estimated at 20-25% of system output. Combining duct leakage, building envelope leakage due to supply/return imbalance and conduction, researchers estimated a "normal" efficiency loss in the range of 30-40% of system output.

Another method of quantifying losses associated with forced air distribution systems was used by Ecotope, Inc., a Seattle engineering firm, to field measure heating system efficiency in 24 electrically heated homes. The method meters energy used by the furnace to keep the house at a given temperature, and compares furnace energy use with the energy used by a battery of zonal heaters to maintain the same temperature. The method used by Ecotope is called an "alternating co-heat test." Zonal heaters are assumed to represent 100% efficiency because all of the heat they produce is delivered to the house. Two measures of efficiency were completed: "heat delivery efficiency": total useful heat delivered through the registers while the furnace fan is on divided by the power input to the furnace [including fan energy]; and "system efficiency": total useful heat delivered to conditioned space during the entire period of furnace cycling, divided by the power input to the furnace [including fan energy]. In this study, infiltration losses through the system while it is off and door closure effects are not included, so the real efficiency of these systems is probably somewhat lower than the measurements indicate. The home sample included 22 homes with at least 50% of the ductwork outside heated space and 2 homes with all ducts inside heated space.

Heat delivery efficiency averaged 56% for the base sample and 67% for homes with interior ducts. Due to recovery of cycling losses and offset of loads due to unintentional heating of buffer zones, system efficiency is higher. System efficiency for the base sample averaged 71%. Homes with interior ducts had a system efficiency of 98%. Efficiency losses due to ducts averaged 29% for the base sample and 2% for the homes with interior ducts. Power loss per cycle averaged 1276 watts for the base sample and 86.5 watts for the homes with interior ducts. Duct leakage to the outside for the base sample was 436 cfm @ 50 Pascals. For homes with interior ducts, leakage to outside measured 21cfm @50 Pascals. [Olson et. al. 1993]

Energy losses measured using the alternating co-heat method [29%] compare well to the energy losses calculated from short term monitoring studies by other researchers [30-40%].

Energy Savings Potential of Duct Repairs

Efficiency losses are a good way to describe the effect of duct system deficiencies, but an equally important question is, Can we effectively reduce those losses with duct repair efforts? Eight studies report reductions in either duct leakage area or duct leakage that lead to efficiency improvements and savings in annual energy use. A table summarizing these results is included at the end of this report. Early studies used different measurement techniques to quantify their results simply because duct testing equipment used in later studies hadn't been invented. However, fine points aside, it is typical to see repair efforts reduce duct leakage by 40-60% in homes w/basements [large portions of ducts inaccessible] and by 60-70% in homes with accessible ducts.

By reducing duct leakage 40-70% researchers were able to achieve 5-10% annual energy use reductions in homes with basements and 10-20% annual energy use reductions in homes on crawl spaces. 15% savings were produced with minimal repairs in 18 small commercial buildings. In rough numbers, with hand sealing approaches in use today, researchers are reducing typical 30-40% efficiency losses by a third to a half, depending on building type. It is important to note that new aerosol based sealing technology, available commercially in late 1997, could significantly improve our ability to deal with inaccessible ducts and improve our sealing percentage to the 70-80% range. Another important consideration is that all of the studies summarized here are based on repairs to existing homes. In new construction—that is, with maximum accessibility—leakage could be very low and efficiency very high. Currently the efficiency measurements by Bob Davis, [Davis et. al., 1996] on new energy efficient manufactured homes may provide a reasonable approximation of what could be achieved in new construction: 85% system efficiency. Aggressive duct repairs in 6 existing site built homes increased system efficiency by 16%, from about 70% before repairs to about 86% after. [Palmiter et.al. 1994] However, no alternating co-heat efficiency measurements have been reported for new homes whose duct systems were aggressively sealed and performance tested for leakage as part of initial installation.

Northwest researchers measured system efficiency as high as 98% in homes with ducts located inside heated space [Olson 1993]. In spite of efficiency advantages, cost and a long-standing and revered tradition of minimal practice represent significant barriers to this approach. Researchers at the National Home Builders Research Foundation [NHBRF] developed cost comparisons for several methods of bringing ducts inside new homes. These methods were competitive, but still involved cost increases over current practice. NHBRF staff strongly agreed with others around the country that if ducts are brought inside, they should be continuous and tightly constructed, that is, building cavities should not be used to transport air. [Lyons and Pesce 1996]

Costs of Duct Repairs

The 18% average reduction in annual energy use achieved in 160 Florida homes cost an average of $200 per home [Cummings 1990]. A 21.8% average reduction in 18 Arkansas homes cost $500 per home, including a materials cost of $39.65 [Davis 1991]. Duct repairs in 5 North Carolina homes were estimated to reduced cooling energy use by 12% or about 250 kWh/yr. and heating energy use by 600 kWh/yr. for an average cost of $200/system [Vigil et. al. 1993]. Ducts in 19 New York and Wisconsin homes with basements were sealed and insulated for a cost of $650 per home. Annual energy use was estimated to decrease 9% due to duct repairs [Strunk 1996]. Repairs to ducts in 25 multi-family buildings in New York resulted in 6-10% annual energy savings depending on basement tightness for a mean cost of $899/ building. Buildings contained 3-5 apartment units each. Mean cost of duct air sealing was $235; mean cost of duct insulation was $644 [Karins et. al. 1997]. Duct repairs in162 site-built homes in Washington achieved average energy savings of 1500 kWh at a cost of $450 per home. Utility administrative costs per home were $160 [Lerman, 1997]. Duct repairs in 387 Oregon manufactured homes averaged $228 per home and reduced annual space heating use by 1258 kWh or 13% [Robison et. al. 1997]. Based on results in 8895 homes, Florida Power Corporation reported average savings of 1000 kWh per customer at an average cost of $114 per home [Results Center 1993]. Costs reported for duct repairs in 25 existing Northwest homes averaged $335; costs of duct air sealing for 41 new Northwest homes averaged $301, although ducts in the new homes were twice as tight as ducts in the retrofit homes. Cost of pressure relief or distributed returns in new homes averaged $403. Cost of heat load calculations and minimal duct design averaged $75 [Haskell 1995].

Typically costs of duct sealing range from $200-$500 per home. Adding duct insulation increases duct repair costs significantly.

In some cases, duct repair costs were used to compute cost to a sponsoring utility of achieved energy savings, usually expressed in mills per kWh: Florida Power Corporation: 30 mills/kWh [Results Center 1993]; Tacoma Power and Light: 17 mills [Lerman 1997]; Eugene Water and Electric Board: 12 mills [Robison et. al. 1997].

In a study of 18 small commercial buildings, cooling energy use was reduced by an average of 15.1% at an average cost of $455. Annual energy savings were calculated at $195/yr for a simple payback of 3.1 years. According to the authors of this report, repairs and results were tightly constrained by project budget and do not represent the full costs or benefits available in these buildings [Withers et. al. 1996].

Effects on the Utility System: Peak Demand Reductions/Avoided Costs

Because forced air systems operate the most when weather conditions are at their worst, duct deficiencies can have an adverse effect on peak power demand. Several studies have estimated demand increases due to duct deficiencies, and several studies have measured demand reductions due to duct sealing programs.

Based on short term energy use monitoring before and after duct repairs in 160 Florida homes, researchers measured a 1.65 kW per house peak demand reduction. Extrapolating this result to the entire Florida housing stock, researchers estimated that reduction in peak demand could equal 13% of the state's generating capacity. Based on cost of repairs, researchers estimated that a statewide duct sealing effort would cost approximately $600 million dollars but would yield a $3.5 billion avoided cost to the utility system. [Cummings et.al. 1990 and 1991]

Based on field measurements in 31 California homes, researchers developed a prototype house and used an engineering model to simulate effects of duct repairs. Based on efficiency losses encountered in the field—30-40%--they estimated that duct deficiencies increased peak demand by 0.8 kW per home with an additional 0.2 kW peak demand increase due to door closure effects[supply/return imbalances]. [Modera et. al. 1992]

After duct repairs in 5 North Carolina homes, summer peak electrical demand decreased by an average of 250 watts/home, or a 12.8% reduction [Vigil et. al.1993].

Peak demand reductions were measured before and after duct repairs in 61 homes that were part of Florida Power Corporation's duct repair program. Peak demand was reduced 0.49 kW/home or 14% of air conditioning load .[Horowitz et. al. 1994]

Based on energy use and weather data for 96 Arizona homes, researchers calculated diversified demand savings of 0.23 kW or 5-7% of pre-repair demand. [Kolb and Ternes 1995]

Other Associated Effects/Benefits of Duct Repair and Improvement

Duct literature tends to concentrate on energy related effects of duct system deficiencies: air leakage, conductive losses, effects on the building envelope, quantified as system efficiency losses or unnecessary annual energy use. Benefits of repairs are likewise predominantly focused on reducing energy losses and improving efficiency of distribution systems. However, duct losses, and in particular the uncontrolled air flows caused by flow/pressure imbalance, can have other effects on buildings and people. [Cummings et. al., 1993]

Health Safety/Air Quality Issues

Homes with combustion devices present special challenges and opportunities for duct improvement efforts. Flow imbalances that depressurize a home, can make it more difficult for combustion appliances inside the home to draft properly. The relatively weak force of "draft" or "stack effect" in a chimney can be overcome by depressurization caused by mechanical system operation. When mechanical systems depressurize a home, outside air reacts by flowing down the chimney and into the home, bringing combustion by-products with it. Wood burning appliances that use house air for combustion are particularly vulnerable and are pervasive in NW housing. Appliances that use outside combustion air are potentially safer, but by no means immune to depressurization [Boe 1995]. Wood stoves that take combustion air from outside the home have backdrafted in negative pressure environments—specially as the fire dies down and draft weakens. [Tiegs and Bighouse 1994].

Newer induced draft , sealed combustion, direct vent gas and oil equipment is usually less vulnerable to depressurization, if the equipment is maintained in good repair. However natural draft equipment—the most vulnerable equipment—is far more common in existing housing.

Forced air systems are not the only appliances in homes that can cause depressurization related health and safety issues. Exhaust devices, dryer use, or a combination of systems operating simultaneously with the forced air system can cause a combustion device to spill potentially harmful combustion gases into living spaces. Combustion devices such as gas water heaters can experience "flame roll out" upon startup in a depressurized environment. Leading national duct repair training centers consistently emphasize combustion safety issues and potential health /safety benefits of properly conducted duct repairs. It may be fair to say that in a significant percentage of homes, the health /safety benefits may be much more important than any achievable energy savings.

Combustion safety issues pose a challenge to duct sealing programs, because for safety and liability reasons, repairs to ducts or to building envelope leaks should not be commenced until unsafe appliances are repaired. Enabling duct fixers to detect safety problems in the field and make appropriate decisions is a key element of training.

In cooling climates depressurization caused by forced air system operation brings humid outdoor air into the building, creating conditions that lead to deterioration of building materials and to growth of molds as well as increasing latent cooling load and cooling energy use.[Cummings et. al. 1991]

Duct leakage can affect air quality and pose health problems even when combustion devices are not present. Since return ducts often run in attics, and since return leaks suck attic air into the return air stream, and since attics contain dust and various types of insulation materials, return leaks can contribute to air quality problems by contaminating houses with particulates from attics. [Boe 1996]

When return leaks result in pressurization of homes or of zones within homes, combustion appliance problems go away—until the leaks are repaired. If this sort of situation is encountered in the field, untrained duct fixers can repair leaks and cause combustion appliance problems where none existed before. Pressurization inside homes drives moisture laden air into wall, floor and ceiling cavities on its way out of the home. As moisture accumulates inside building cavities, wetting of the building materials can lead to mold growth and structural decay. Siding and exterior finishes can be damaged as moist air is forced through wall cavities by pressurization. [Cummings et. al., 1993]

Training/Quality Control

Two recent studies of NW duct repair programs mention the impact trained, experienced, reliable duct fixers can have in achieving cost effective energy savings [Robison 1997 and Lerman 1997]. Trained duct fixers can minimize safety and liability problems because training enables duct fixers to detect safety problems before they start and to verify that repairs have been safely accomplished before they leave the job. Training proposed for the NEEA/EPRI project will enable/require trained technicians to fill out and submit a record of the tests they perform and test results they achieve. It is anticipated that test records will be used as the basis of a quality control review process and ultimately as the basis for contractor certification. In a large California project, quality control based on results of diagnostic tests was automated with software to more speedily review data and to collect/quantify overall program accomplishments. [Downey 1994]

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