Municipal Energy Analysis Report:

Clean Energy Site Assessment

For

Gill, Massachusetts

July 28, 2018

Prepared by
Ben Weil, Extension Assistant Professor of Building Energy
and
Simon Periera, UMass Clean Energy Corps

UMass Clean Energy Extension
209 Agricultural Engineering
250 Natural Resources Way
Amherst, MA 01003-9295
413.545.8510

https://ag.umass.edu/clean-energy
energyextension@umass.edu

Introduction

The town of Gill invited the UMass Clean Energy Corps to investigate the Elementary School for potential energy savings, improved comfort and functionality, and if possible, transition toward renewable energy. The UMass Clean Energy Corps is a group of students trained in building science and energy analysis, working under the direction of Professor Ben Weil, and affiliated with the UMass Clean Energy Extension. On April 19, 2018 the Corps visited the Gill Elementary School. Claire Chang of the town Energy Commission and Principal Conor Driscoll were present.

Targeting the Elementary School

Of all municipal buildings, the Elementary School is the largest energy user, with energy use dominated by fuel oil for heating. In fact, fuel oil for the elementary school is the single largest energy account for the town. The building has a heating Energy Utilization Index (EUI) of 52 kBtu/sf, which is roughly 18% more energy intensive than the median school in the northeast.

Description of town priorities

The town has sought help in pursuing their goal of reducing energy use by 20%. The school water system is a source of health concern and potential large expense. One goal is to reduce first cost for any water treatment solution, and to arrive at a solution with low operating expense. If possible engineering or equipment synergies for solving both energy use and water treatment problems should be pursued.

Purpose of report

In this report we specify certain energy conservation measures and retrofits and associated energy savings. Where possible, we provide cost estimates. However, costs have been known to vary by more than 100%, and so it is always advisable to get multiple estimates or proposals for any given retrofit measure. Similarly, the report contains recommendations for certain materials, assemblies, or HVAC components. There are often multiple ways to accomplish the same functions, and a contractor may suggest approaches that may work better, cost less, or are simply preferable to that particular contractor.

Underlying Models, Weather Normalization and Assumptions

This report summarizes findings relating to energy use and suggests changes to the building envelope, mechanical systems, and operational choices that can reduce it. Estimates of energy use and potential energy savings are based on energy models built to reflect the specific characteristics of the building. These models are calibrated using actual energy use and weather data allowing a relatively high level of confidence in the accuracy of the results from recommendations. The base building energy model developed for the Elementary School examines oil usage only, and deviates from actual heating energy usage by only 0.34%.

Weather normalization is a technique to control for the variations in weather. Changes in energy usage due to proposed measures are projected for an average year. For Gill, we used a 5-year average of heating degree days at a range of balance point temperatures from 44°F to 65°F from a weather station near Greenfield High School. Degree day data were downloaded from degreedays.net. For cost and savings estimates we used the 2017/18 season average fuel oil price of $2.50, and average electricity price of $0.18 per kWh.

Summary of potential changes

In this report we describe recommended changes to the thermal envelope of the building. Uncontrolled air leakage can be dramatically reduced by installing a complete air barrier at the ceiling. Currently uninsulated walls can be cost-effectively insulated from the interior. The highly conductive aluminum panels that make up a portion of the exterior walls can also be retrofitted with insulation, while leaving the existing windows in place. Installing modular heat recovery ventilators in the classrooms would provide an additional 13% heating energy savings while also improving the indoor air quality and learning environment. Finally, we propose replacing the current steam boilers with modern heating systems. It may be possible to use the existing water well to provide ground-water source heat pumps to heat and cool the classrooms efficiently and quietly. If this is feasible, then it may be possible to use the well pumps for the heating system to also drive the water supply and purification system. The total energy reduction due to envelope measures, heat recovery ventilation and high efficiency of ground source heat pumps would be 86%, with cost savings of approximately $12,000 per year. With additional revenue from Alternative Portfolio Standard payments around $5,000, the simple payback period for the entire investment would be about 7 years.

Current Conditions

Gill Elementary school is a long single level building running north to south with classrooms on either side of a central hall way and a cafetorium with a cathedral ceiling to the north running perpendicular to the rest of the school. Administrative offices, kitchen and custodial store-room and office are adjacent to the cafetorium. The basement houses a boiler, well water pumps and pressure vessels, and general storage. The boiler is an oil-fired steam boiler. The steam system serves the original school area, and a shell-and-tube heat exchanger generates hot water that circulates for hydronic heating system for the addition. The building exists largely as it was built in 1953, with an addition in line with the original that appears to have been added in the 1980s. There have been some changes. Cellulose insulation was added to the attic at some point in the past, but air sealing was not done. The original large single pane floor-to-ceiling windows in the original classrooms were replaced with aluminum panels with double-pane windows integrated. Classrooms are heated and fresh air is supplied by unit ventilators. Exhaust air is extracted by two air handlers with ducts running to each classroom. Bathrooms and the kitchen have their own air exhaust fans. The cafetorium and kitchen are served by an air handler with a steam coil and a fresh air intake. The motor is the same vintage as the building. Domestic water is provided by a well that has tested positive for some contaminants and thus the school only provides drinking and cooking water from delivered water. The school is obligated to solve this problem, and most solutions are costly and energy intensive.

Problems

Conductive heat loss through the CMU and brick walls

The cement masonry unit (CMU) and brick walls make up a large portion of the school's surface area, and are uninsulated, with a resistance to heat flow around R-2.93 $°F \bullet hr \bullet ft^2/Btu$ (see Figure 1). We calculate that the CMU and brick walls cover roughly 5600 square feet of surface area and account for about 31% of the total building heat loss. Currently these walls contribute to roughly 280 MMBtu of heat loss annually. With the current oil-fired boiler, heat loss through the walls costs roughly $7240 per year.

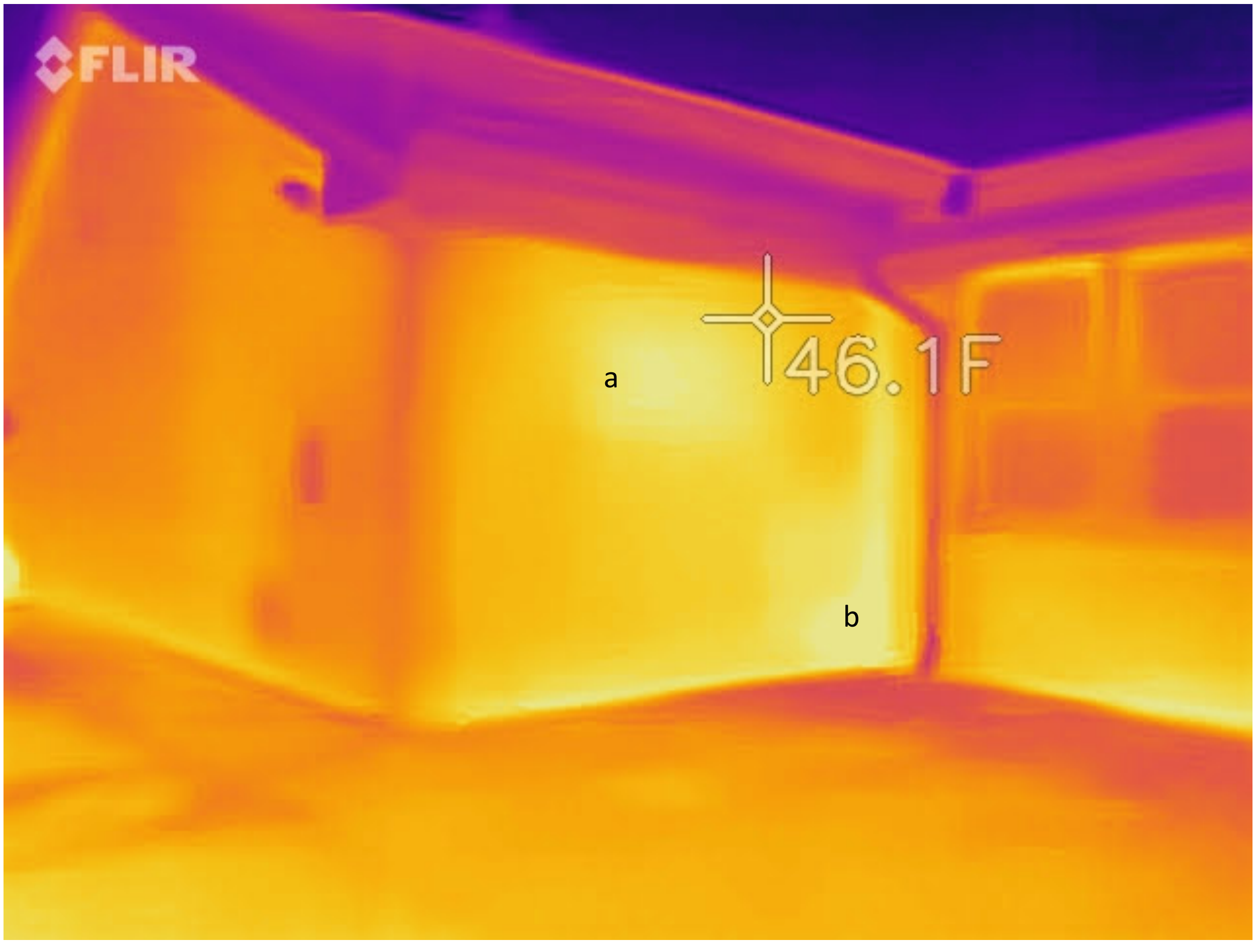

Figure 1: Thermographic image of cafetorium and kitchen exterior walls. Note the hot spots labeled "a" and "b". These are the locations of the compressors for standing refrigerator and freezer on the inside. This is an illustration of the rapid heat transfer thorough the uninsulated wall.

Air leakage especially through ceilings

Cracks and unsealed openings in the ceilings in the building envelope causes inside air to exfiltrate and outside air to infiltrate. In particular, there is no dedicated air barrier at the ceiling. In the older portion, the ceiling is loosely attached Homosote tiles (see Figure 2a). Not only are the tiles themselves air permeable, but seems between the tiles are all cracks open to the unconditioned attic. In the newer part of the school, above the suspended ceiling, there are simply kraft-faced fiberglass batts stapled to the bottom chord of the roof truss, with some furring attached to keep it in place. Fiberglass does not resist airflow, and there is no sealing material attempting to knit together the kraft facing into an air barrier (see Figure 2b). The cellulose insulation that has been installed on top of the original stapled-in place fiberglass batts (the older section has foil facing) does impede air flow somewhat, so while it is not an air barrier, it does act as an air flow retarder, reducing the air leakage from what it would be without the cellulose in place. Annual heat loss through air leakage is 117 MMBtu, 13% of the school's total.

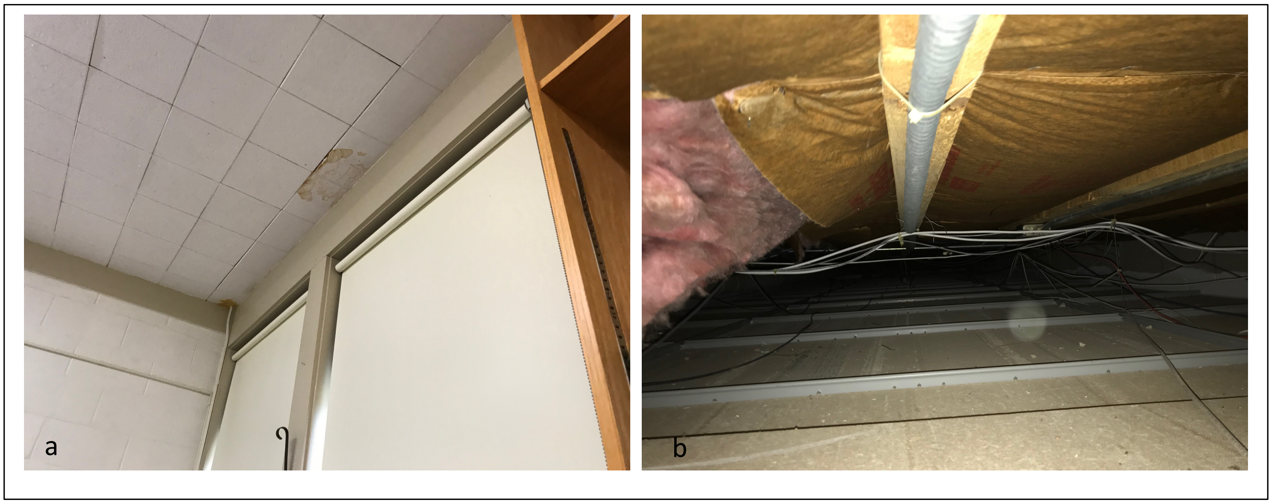

Figure 2: (a) Homosote tile ceiling and (b) fiberglass batt with no air barrier

We estimate that the uncontrolled air leakage rate averages almost 750 cubic feet per minute (CFM). This is about 0.25 air changes per hour (ACH). While not out of line with air leakage from a newer building, the location of the air leakage is primarily at the ceiling, which causes durability problems and reduces the effectiveness of the fibrous insulation. Warm indoor air leaking into the cold unconditioned attic brings moisture which can condense on the underside of the sheathing. This can cause mold growth and can reduce the service life of a shingled roof due to degradation of the shingle itself as well as undermining the attachment holding power of the roofing nails. Generally, it is advisable to complete a ceiling air barrier before investing in re-roofing. Additionally, convective air movement through the insulation undermines the insulating performance of fibrous insulations. The insulating effect is caused by the ability of fibrous insulations to trap small spaces of still air. If air is moving through the insulation, then by definition it is not still. This windwash effect can reduce effective R-value by as much as 90%. Given the composition and layers of fiberglass and cellulose, we estimate closer to 10% windwash de-rating. So the lack of an air barrier is responsible for an additional 12 MMBtus of heat loss annually, costing roughly $335. While not large, relative to the overall heating bill, it suggests an additional benefit to providing an air barrier at the ceiling.

Ventilation heat loss and inefficiency

The next largest heat loss, at about 12% of the total is due to ventilation. Ventilation is often a very large and accepted energy cost for educational facilities. It is absolutely vital that sufficient fresh air is provided for all people in the facility, and the population density of schools is often much higher than for other buildings. Fresh air is currently inducted through openings on the outside of each classroom and pulled with fans through the unit ventilators, where it is mixed with return air from the room and passes over a heated coil to warm to the room discharge setpoint. Room air that has already been conditioned is exhausted from each classroom via one of two air handling units that exhaust out the roof. The energy that was used to heat this air is, thus lost. There is also considerable electrical energy expended to move the air both at the intake and at the exhaust. In addition, there are large exhaust fans for the bathrooms and the kitchen. Air exchange is also effectuated through the air handler that serves the cafetorium.

We calculate that the occupied ventilation rate of Gill Elementary is about 700 CFM. This creates an annual heat loss of 109 MMBtu, costing $2800. It also imposes an electrical cost nearly 9200 kWh, or $1650 per year.

While the cost of ventilation is high, this rate of ventilation is actually low. To meet current standards, the ventilation rate should be much higher. If we assume 20 people per classroom, the total required ventilation would be 2000 CFM (calculated by area, the required ventilation is about the same). There is a great deal of evidence that insufficient ventilation impedes learning and school performance and that increasing ventilation rates can improve learning, concentration, higher cognitive skills, and reduce transmission of airborne illnesses.[1, 2] Thus, we will propose solutions that can increase necessary ventilation and match it to actual room occupancy, reduce unnecessary ventilation, and recover heat energy on ventilation air.

Conductive heat loss through panels and windows

The windows and the panels in which some of them are installed are other surfaces with considerable heat loss. Both have R-values less than 3, meaning they provide very little thermal resistance, allowing the heat to flow out of the building easily. The panels account for 820 square feet and contribute to an annual heat loss of 46 MMBtu, or about 5% of the total. Windows, both conventionally installed and those incorporated in the aluminum panels, account for 1170 square feet and contribute to 58 MMBtu or 6% of the total. With the current oil-fired boiler this amounts to heat loss costs near $1200 and $1500 respectively. However, it is worth noting that the windows have been replaced in the past and that they are modern 2-pane windows and unlikely to warrant replacement anytime soon. In fact, the windows, perform slightly better than the panels in which they are incorporated (see Figure 3).

Figure 3: thermographic image indicating heat loss through panels is larger than through windows

Conductive heat loss through ceilings

There are two ceiling areas: the flat main ceiling above the classrooms and offices, and the cathedral style cafetorium/gym ceiling. The main ceiling covers 14300 square feet and the cafetorium ceiling has a surface area 3540 square feet. The main ceiling differs between the older and newer sections as described above. The newer section, which is about 40% of the main ceiling has 6 inches of fiberglass insulation covered with another 4 inches of cellulose insulation, but lacks any air barrier. From the wooden joists in the new section wires, attach to hold the drop ceiling. In the older portion of the main ceiling, 8 inches of cellulose cover the homosote ceiling, resting on an occasional foil vapor barrier. Currently it has an effective R-value of 27 and contributes to 76 MMBtu of heat loss annually. This is 8.5% of the total heat loss and accounts for about $2000 in annual fuel costs. The gym ceiling is a compact roof with an estimated R-value of 32 and contributes to annual heat loss of 16 MMBtu, or $417 a year.

Steam boiler and hot water conversion inefficiency

The second largest source of lost energy is the inefficiency of the steam boiler and hot water conversion. On an annual fuel utilization efficiency (AFUE) basis, the oil fired boiler is at most 84% efficient. Steam boilers of this age are usually closer to 78% percent efficient. With about 1/3 of the heating load met by converting steam to hot water and pumping it to the newer section of the school, we estimated boiler efficiency at 80%. This means that 20% of the heating value of the oil purchased is lost up the exhaust stack. This amounts to an average 178 MMBtus, or roughly $3700.

Solutions

The following are some possible solutions to the problems and opportunities we identified. We think these are the least-cost, most easily implementable, and effective choices, but it is possible to devise other solutions that may be similarly effective. All energy and financial savings for envelope and ventilation solutions are reported with the assumption that the existing heating plant remains in place. Energy and financial savings for replacements for the current heating plant are based on the assumption that the envelope and ventilation measures are implemented, so savings are relative to keeping the existing heating plant, and not relative to the total current heating energy use and expenditure.

Insulate CMU walls from the interior

We recommend insulating the CMU walls from the interior, this will retain the aesthetic and low maintenance exterior finish of the brick walls. We recommend attaching insulation board to the interior of the CMU wall and finishing it with gypsum board, the R-value is increased from about 3 to 27. Since the interior CMU walls continue to intersect with the exterior wall, there will continue to be higher heat loss at these intersections. Thus, the effective R-value of this retrofit approach is closer to 20.

We recommend a system for attaching foam boards and finish materials to an existing masonry wall, that is robust and uses conventional materials and techniques. However the details are important to get right. First, 2x4 wood studs are installed “on the flat” using masonry screws at 26½-inches on center to allow a 24-inch space between them. These provide the attachment points for the other layers of insulation and interior finish materials. We recommend foil-faced polyisocyanurate foam boards. In each newly created stud bay, foam board of 1.5 inches thickness and 24 inches width is installed. It can be adhered to the CMU wall or just pressed into place. On top of this, and overlapping the studs 2-inch foam boards are attached. Foam boards are attached to the studs with long screws running through 1x4 furring strips, which act as “washers” to keep the foam compressed in place without “pull-throughs”. All seams of this top layer of foam board should be sealed with high quality pressure sensitive adhesive tape. The entire perimeter of the foam board wall covering should be sealed with tape or one-part foam to the connecting air barrier (floor, interior walls, ceiling, etc.). This is critically important for the durability of the wall, for preventing freeze-thaw risks to the exterior brick, and preventing mold growth behind the foam. The furring strips create a service cavity in which to run electrical and other wires. Gypsum board is then attached to the furring strips, and finished conventionally. Schematics of this wall detail are in figure X.

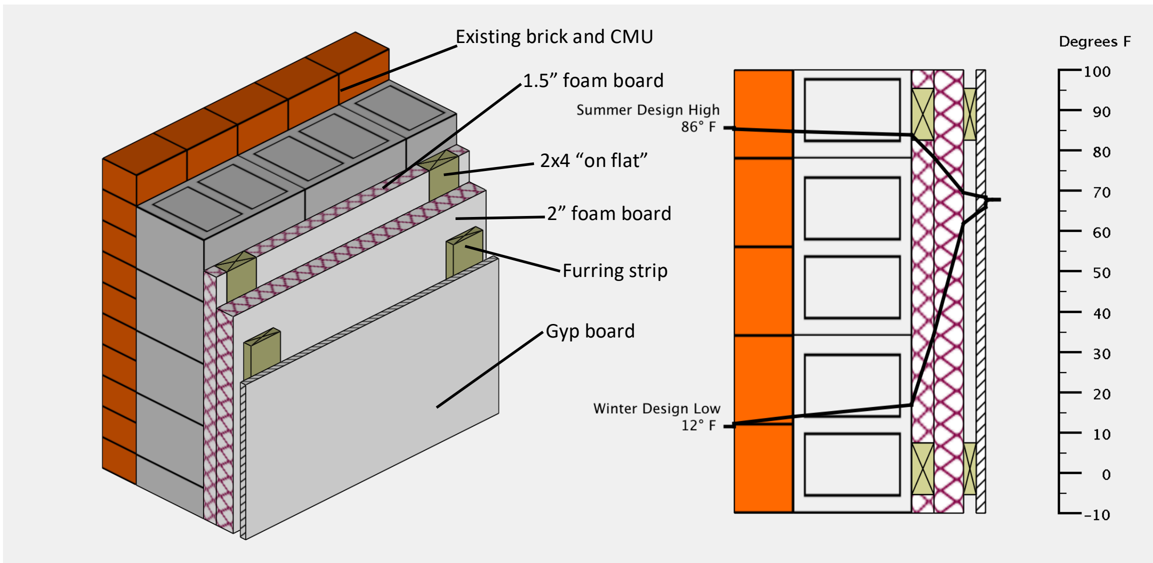

Figure 4: Axonometric and section view of interior insulation solution

Overall savings from this measure would be 298 MMBtu, or roughly $6200. The implementation cost, which includes materials and installation is about $33,660. The breakeven point for this fix is just between 5 and 6 years. This is the single largest heat loss reduction measure, and with the high energy savings and a quick payback period we strongly advise implementing this measure.

Provide air barrier at ceilings

Older section: Gypsum board and paint

In older section of the school, where the current ceiling is Homosote tiles, a complete air barrier can be provided by adding a gypsum board ceiling, screwed directly through the existing ceiling tiles and into the existing wood strapping. An important detail is to seal the gypsum board to the surrounding interior walls to form a complete air barrier. If air sealing tape is used, it can be hidden using crown or other molding. The gypsum board should be mudded and taped and painted with latex paint.

Newer section: complex combined measures

To cost-effectively fabricate an air barrier on the newer section of the school, where there is a suspended ceiling, we think that the best solution will necessarily require careful and thoughtful work by contractors using a variety of materials and methods. In all cases, the ceiling tiles will have to be taken down and set aside to be reinstalled after work has been completed. In most of the space (for instance, above the classrooms), there are relatively few obstructions aside from the wires suspending the ceiling grid. For these areas the least cost solution will is to slide long strips of an air barrier membrane up above the ceiling grid and staple it to the ceiling joists and/or strapping as appropriate. We think that a low-cost, vapor-open, and tear-resistant material like Typar is appropriate. The membrane strips will need to be slit to fit around the ceiling grid suspension wires. All membrane seams should be sealed with the manufacturers' approved tape. Penetrations (including the ceiling suspension wires) should be sealed with flexible tapes, acoustical caulk, or other flexible sealants. In some locations gaps will need to be filled with other materials including one-part foam. For some areas, where there are a lot of obstructions, it may be simpler or more cost-effective to use a 1-inch lift of closed cell spray foam to fabricate an air barrier. Because this material is expensive to install its use should be minimized.

Finally, the interior wall-tops need to be sealed from above—up in the attic space—using one-part gun foam and conventional air sealing techniques.

Our model estimates overall annual savings for air sealing at the ceiling plane in the main part of the school between 88 and 117 MMBtu ($2200 to $2800) depending on how well the solution is implemented. Costs will range from $25,000 to $40,000 depending on how much closed cell spray foam is required. We estimate that no more than 20% of the newer section ceiling will require this material, so the cost is estimated at $28,000. This puts the payback period for this measure between 9 and 13 years. However, we highly recommend this measure since it protects roof durability (avoiding future maintenance costs), is part of a plan that significantly improves air quality, and by significantly reducing heating (and future cooling) demand, this measure enables first-cost savings for advanced space conditioning systems.

Implementation timing

We recommend that wall insulation and ceiling air barrier construction be implemented together. This will allow ceiling air barriers to connect to the new wall air barrier. Also, since both measures involve gypsum board installation and painting, it makes sense to have a single contractor do that as a single project. It is possible to separate out the air barrier construction in the newer section, since it does not involve drywall. However, it is important that a strip of wide air barrier material be left in place and accessible above the level of the suspended ceiling so that it can be tied into the new ceiling air barrier when it is constructed.

Panel and window

option 1: replace with new curtain wall glass and spandrel

This is the first of two potential options. This is the pricier, but much more elegant looking option. We recommend totally removing the panels and windows and adding a new curtain wall made of glass and spandrel glazing. This would be an expensive implementation, but would be true to the original architectural vision. With a payback period longer than 20 years, this would be difficult to justify on purely energy-saving grounds.

option 2: add foam board and interior finish to existing panel leaving window in place

The second option less elegant and aesthetically pleasing, but is much more cost effective. In the interior we suggest adding foam board and a finish to the existing panels. The windows would remain in place. One product that would make this installation simple is Insofast Panels. These are interlocking EPS foam panels with plastic studs embeded in them. The panels can be affixed to the aluminum skin of the exisiting panels using modern adhesives. No screws or other mechanical attachment is necessary. Interior gypsum board and wooden trim can be attached to the embeded plastic studs. The cost of implementation would be roughly $3800. Annual savings would be 46 MMBtu, or about $960. The breakeven period is 4 years, making this a high priority solution.

Increase insulation at ceiling level

At the ceiling level one could bring the insulation value up to modern code by adding 6 inches of cellulose insulation on top of the existing insulation on main ceiling. This measure would produce annual savings of 29 MMBtu or $624. The implementation cost is roughly $17,000. With a payback period of 27 years we do not recommend this measure as a high priority. However, it may be possible to fund the additional insulation, and it should be considered as part of an overall heating demand reduction package. As the largest surface area, the ceiling will be the largest contributor to heat loss in the future—assuming the higher-priority measures are implemented.

Increase insulation in gym/cafetorium ceiling

It is possible to add 8 inches of insulation between the current rafters of the cathedral ceiling. This would essentially double the R-value. However, the savings would be small ($183 per year) and the implementation cost would be relatively large (about $21,000). We do not recommend this measure at this time. However, when it comes time to re-roof the school, it may make sense to add a layer of nail-base (roof sheathing with foam insulation adhered to it) to increase roof insulation in conjunction with that project.

Mechanical systems

If the school implements the recommended envelope measures, design heating demand will be reduced by up to 55%. This presents the school with two distinct opportunities for even greater reductions in energy use and the potential to shift the school's energy budget almost entirely to renewable energy. With a lower demand comes the opportunity to replace the existing inefficient and oversized steam boiler system with a much smaller (and thus less expensive) high-efficiency heating system. With improved air barrier and the relative reduction in heat loss due to other factors, the benefits of heat recovery ventilation and improved ventilation controls become more apparent. Also, due to the timing of work being done on the school including new flooring and, as we recommend, insulation of the walls the heat distribution system should be upgraded to accommodate a high efficiency heating system at the same time, since the unit ventilators would have to be partly disassembled to accommodate the other measures.

Ventilation

Ventilation currently accounts for about 12% of the heating demand, but after implementation of envelope measures, ventilation will be the single largest component of demand at 33%. This is typical for modern school buildings. With large populations of children, adequate ventilation is vital for health and learning. The energy cost associated with exhausting conditioned air and conditioning outside air is accepted as a necessary cost of providing adequate ventilation. However, with energy recovery ventilators, one can recapture most of the heat lost on ventilation air, and, depending on configuration, dramatically reduce the fan power required to move the ventilation air and more tightly control the ventilation system to serve actual demand.

The current ventilation system for the classrooms uses the unit ventilators on the exterior wall to bring in outside air, pass it over heating coils and deliver it to the classroom. There is a common exhaust air handler that pulls a roughly equivalent amount of air out. Each unit ventilator has a ¼ horse power fan motor, so for 10 classrooms the supply fan power is 1.86 kW. The exhaust air handlers have to overcome considerable duct friction so total power draw is about 1.8 kW, about 3800 kWh or just under $700 per year. There is additional ventilation air provided by the large air handler that serves the kitchen and gym/cafetorium. At 748 W, this air handler costs about 1560 kWh or $280 per year to operate. Based on pressure diagnostics, and our best inference from energy use regression modeling, the overall ventilation system is providing about 700 cubic feet per minute (CFM) during occupied hours. This represents a loss of about 109 MMBtu or roughly $2800 per year. Overall, the current ventilation system uses 140 MMBtu in electrical and heating energy combined, about $4500 per year.

Despite its high cost, the system is probably under-ventilating the school. Based ASHRAE standard 62 and an assumption of 20 people per classroom, the ventilation system should provide an overall ventilation rate of 2000 CFM. However, we estimate that the system is only providing around 700 CFM. Because of the uncontrolled air leakage, mostly through the ceiling, the overall air exchange rate is about 1400 CFM, which is much closer to the required ventilation. However, once air leakage is controlled by creating an air barrier at the ceiling, increased ventilation will be required. Abandoning the current inefficient ventilation strategy and replacing it with highly controllable and efficient heat recovery ventilation equipment—separated from heating distribution—is an opportunity for large energy savings, an improved learning environment, and healthier indoor air quality.

The simplest solution for the classrooms is to provide each classroom with its own, standalone heat recovery ventilator (HRV). Each one would provide the correct amount of fresh air as required by classroom conditions, while recovering 80 to 90% of the heat that would otherwise be lost on exhausted stale air. Many HRVs can be controlled with a carbon dioxide sensor that increases ventilation in direct proportion to the number of breathers in the room. This prevents unnecessary ventilation (for example, when the room is unoccupied) and also assures sufficient ventilation even when the population increases. One product we think would satisfy these conditions is the Ventacity VS500SQ. It is ductless, quiet, and very energy efficient. The ductless and modular installation and wireless controls make it much less inexpensive to install than ducted systems. This sort of installation would also be easy to integrate into the wall insulation solution proposed in this report since it only requires two 10-inch diameter holes and a small hole for a condensate drain.

A vital part of this plan would be to ***close off and seal both the through-wall air intake*** for the current unit ventilators and to ***disconnect and completely seal off the exhaust fans and ductwork*** that serve the classrooms.

Retrofitting the cafetorium ventilation system to include heat recovery would be more difficult and would have less benefit than simply improving the controls for the ventilation and heating system for that zone. We recommend replacing the original motor with a premium efficiency motor and a variable frequency drive. By allowing the motor to slow when less air flow is needed roughly 45% electrical savings is possible.

The modular HRVs in the classrooms would reduce annual electric usage for classroom ventilation to 253 kWh and by recovering heat, cut heat loss through ventilation by between 80 and 91%. The electrical savings by improving the motor serving the cafetorium would be about 55 kWh per year. The total energy savings from the HRV installations and the improved operation of the cafetorium ventilation would be 89 MMBtu (electrical and heating) or roughly $3960 per year. At a cost of $1500 per classroom and $2000 for the new cafetorium-serving motor and drive, the simple payback period on ventilation upgrades would be 4 to 5 years. This measure could be implemented at any time regardless of other measures, but it would make sense to implement it in conjunction with the exterior wall insulation retrofit.

Modern Heating System Options

The current boilers produce steam that directly provides heat to a steam coils in air handling units and unit ventilators in some classrooms. Heat is also transferred from steam to water to provide heat to unit ventilators in the newer part of the school through hydronic supply and return piping. Maximum efficiency for such a steam boiler system combusting heating oil is around 81%. Modern standard hydronic boilers can achieve typical efficiencies closer to 86%, and there are now condensing boilers that can combust a variety of fuels and achieve 94% efficiency. After envelope measures are implemented, the school may be an ideal candidate for a ground source- or water source- heat pump. This would have the benefit of operating on electricity, which can be sourced from local renewable sources. A ground source heat pump could have an efficiency of 300 to 600 percent (coefficient of performance or COP between 3 and 6). However, for these efficiencies to be realized, the distribution systems must be hydronic (circulating water) and use relatively low temperatures (return temperatures below 130°F). In the case of heat pumps, a combination of hydronic and refrigerant-based distribution systems is possible. The current distribution system is mostly steam, so any move to replace the current heating system would have to include changing the most of distribution system.

Wood Pellet Boiler

Wood pellet boilers are heavily promoted by the Mass CEC and other agencies and programs, with very large rebates and a good deal of technical assistance. Wood pellet boilers typically have a combustion efficiency of around 86%, which is a small improvement over the current system. Wood pellets are delivered in bulk and are of uniform shape, size, moisture, and energy content. This would require a location for a pellet storage silo and a large thermal storage water tank. If the steam boilers are removed, there should be adequate space for both. Operating a wood pellet boiler would save 21 MMBtu per year (about 7%) over and above the savings due to recommended envelope and ventilation measures. However, because wood pellets currently cost less than fuel oil on an energy content basis, cost savings would be higher – about $3500.

Wood pellets are considered to be a renewable energy source. They are a byproduct of other wood harvesting and processing activities. Using the accounting approach endorsed by Massachusetts DOER, wood pellet combustion systems reduce carbon emissions by about 60% compared to fuel oil *over a 30-year period*. Installation costs are heavily subsidized and there is a credit under the Alternative Portfolio Standard (APS) program available for each Megawatt-hour equivalent of pellet heating used. Assuming envelope measures are implemented, so that the boiler is sized at about 136 kBtu/h, annual APS revenue should be around $1900.

To use a wood pellet boiler, the entire heat distribution system would have to be converted to hydronics. In the newer part of the school, the unit ventilators are already supplied by hydronic piping. In the older part of the school, this would necessitate new hydronic piping and new radiators or fan coils. These would replace the obsolete unit ventilators.

With the $17,000 in rebates from Mass CEC, the installation cost should be around $42,100, so that simple payback period is about 12 years.

Ground Source Heat Pump

Ground source heat pumps are the most energy-efficient way to provide heating and cooling. By using the relatively constant temperatures of the earth and/or ground water, a heat pump moves low-grade stored solar energy from the ground and using a refrigerant and compressors and pumps, raises the temperature to useable temperatures for space conditioning. As the amount of renewable energy on the New England power grid increases, the carbon emissions associated with using electricity decrease. Using heat pumps (ground source or air source) enables a facility with contracts for sufficient solar or wind energy to be unambiguously free of carbon emissions on an annual basis.

One reason why ground source heat pumps (GSHP) are less frequently chosen than other heating systems the very high initial cost. While the equipment itself is not particularly expensive—in fact it is often significantly less expensive than new fossil fueled boilers and distribution systems—the expense of excavating for a horizontal geo-exchange field or drilling boreholes for geo-exchange loops is often prohibitive. However, if ground water from a standing column well can be used, then the cost of the heat-exchange loop component is greatly reduced.

In the case of the Gill Elementary School, the existing water well and associated piping might be directly usable to implement an open loop standing column ground water heat exchanger. It is also possible that a new well-pump, serving the water source heat pump (WSHP) could also do double duty in providing both potable and non-potable domestic water and thus contribute to solving another issue for the school (as detailed in a later section). To assess the viability of repurposing the existing water well as an open loop heat exchanger requires expertise in hydrology, geology, and water quality. There are many engineering firms that specialize in geothermal and ground water assessment. We highly recommend that Gill pursue a feasibility assessment with one of these firms.

Assuming that use of the existing well is possible, there are several possible ways to structure heat and cooling distribution. Given that the newer portion of the school already has hydronic supply and return piping, it makes sense to re-use this distribution system. Hydronic distribution is a common approach used with GSHP and a water to water heat pump is quite straightforward. Heat pumps work best with low water temperatures (below 120°F). The existing heating coils in the unit ventilators are designed to be used with high temperature water (about 180°F). To provide a direct substitution of the boiler with a GSHP hydronic coils with much greater surface area would be required. However, because the heating demand will have been significantly reduced due to wall insulation, air sealing, and heat recovery ventilation it is possible that the existing heating coils can be re-used with no (or minimal) additional water-to-air heat-exchanger surface area.

In the older portion of the school, the heat distribution uses steam. This is incompatible with low temperature water-based distribution from a GSHP. One solution would be to replace all the steam radiators and heating coils with low-temperature hydronic radiators or fan coil units, similar to what would be required by a pellet boiler. However, the water source heat pump system offers another option, which is to use refrigerant as the working fluid. Similar to “mini-split” ductless heat pumps, a variable refrigerant flow (VRF) system can work dynamically with the water source heat pump to optimize heat distribution. A VRF system uses constantly variable fans, compressors and expansion valves to achieve very high efficiencies, adding about 10% greater energy savings compared to a ground source heat pump alone. Because of the use of modular indoor units, refrigerant distribution boxes, and small, flexible pre-insulated copper tubing 1.5 inches in diameter or less instead of 3-inch hydronic piping, the VRF distribution system is considerably less expensive and faster to install than a hydronic-based system. Another benefit of any heat pump system is the ability to provide cooling, which is likely to become increasingly necessary during the school year as global warming progresses.

Assuming the use of the existing well, the cost of implementation would be $43,000 after the CEC rebate. Annual energy savings would be 239 MMBtu. However, because the school would be switching to a more expensive fuel (electricity), the annual financial savings would be less impressive, at about $4000. With revenue from the APS program of $5300, the total annual savings would be more than $9200 making the payback period just under 5 years.

Air Source Heat Pump

If using the existing well for heat exchange will not be possible or will not have sufficient capacity to heat the entire school, air source heat pumps (ASHP) may be a very attractive and less expensive option for all or part of the school.

The most efficient implementation of ASHP for a building of this size and complexity is a VRF system. While it is possible to size and design a VRF system for the building as it currently exists, we recommend implementing as many as possible of the envelope and heat recovery ventilation measures detailed in this report. And, regardless of what heating system is provided, we recommend modular heat recovery ventilation for all classrooms. The reduced heating load will reduce the first cost and the operating cost of the VRF system.

The ASHP option is slightly less efficient than the GSHP option (averaging about COP=3), but may also be less expensive to install. We estimate that the simplest VRF heat pump system will save 219 MMbtu, or about $4500 annually when the APS payment is included, and cost about $30,000 to install. With a payback period of 7 years, this is still an attractive option—but only if the GSHP option is infeasible or cost prohibitive.

There are many possible choices for indoor units with VRF systems (whether air source or ground source heat exchange). In the newer portion of the school that already has a suspended ceiling, it makes sense to use four-way cassettes, that are designed for suspended ceilings. In the classrooms where new gypsum board ceilings should be installed (to act as an air barrier), any of the wall or ceiling mounted units are viable and are likely the lowest cost choice. It is also possible to use floor-mounted units or even to retrofit “hidden” slim-duct units in the existing unit ventilator cases, though this would sacrifice potential shelving space. Some options shown in classroom settings are shown in Figure 5.

Figure 5: Indoor units in classroom settings: 4-way ceiling cassette, ceiling mounted unit, wall mounted unit

Mixed Systems

Depending on well and groundwater evaluation, it may turn out that the most cost-effective solution will be a combination of several of these systems. New air-source VRF systems can supply hybrid distribution boxes. In this case, locations that already are served by hydronic distribution systems can continue to use hydronic (possibly with panel radiators instead of unit ventilators). A back up boiler can provide additional capacity to both the direct hydronic distribution and, through heat recovery, serve the refrigerant distribution areas as well. Figure 6 shows is a schematic illustration.

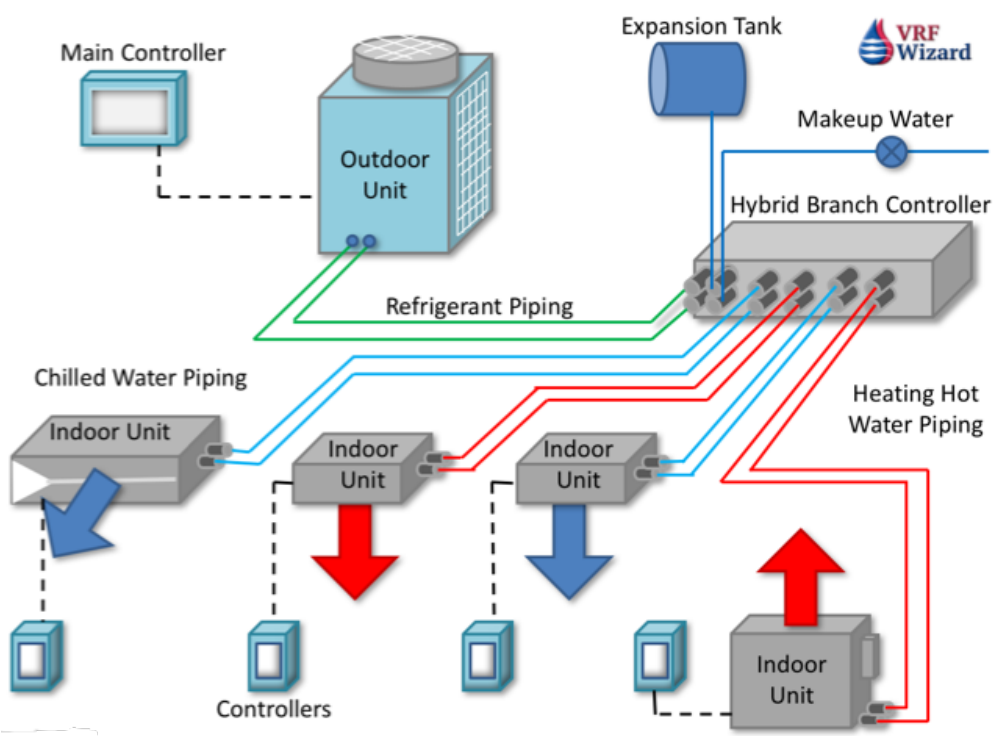

Figure 6: Hybrid VRF system. Credit: VRF Wizard

If the heating capacity of the existing well is sufficient to heat the cafetorium area only, it may still be an excellent choice for the section of the building now served by a large ducted air handler and steam coil. There are several conventional water-to-air heat pumps that could be directly used and retrofit into the existing duct system. For the classrooms currently served by steam coils, ASHP VRF or simpler multi-split ductless heat pumps could be installed. For the classrooms currently served by hydronic distribution, it may make sense to install a properly sized boiler to serve those loads. The boiler can also provide boost heating to the VRF system during peak demand periods.

HVAC Design Considerations Specific to the Educational Mission

There are other benefits to VRF systems that are particularly advantageous in school settings. These include low noise and classroom specific control.

Noise

Unlike the current unit ventilators, VRF indoor units are very quiet. Unit ventilators have typical sound levels of 54 to 67 dB(A) (somewhere between the sound pressure of a teacher's voice and a vacuum cleaner)[3] . Wall mounted VRF indoor units typically operate between 32 and 35 dB(A) (in the range of a whisper or a library). There is considerable research indicating that young children are inefficient listeners who are still developing their speech perception abilities and have difficulty understanding and concentrating on speech in noisy rooms. Teachers voices are usually in the range of 50 to 65 dB(A) depending on the location of the child and the speaker [4] . By reducing the background noise due to the HVAC systems, it is possible to improve teaching and learning. The current ANSI standard recognizes this and specifies a maximum level of 35 dB(A)[3]. The modular HRVs we recommend also comply with this standard, operating between 25 and 35 dB(A) under normal conditions.

Controllability and zoning

Each VRF indoor unit operates as its own zone and can be tightly controlled by the teacher in each room independently of other rooms. With occupancy sensors standard, they also will setback to save energy when rooms are unoccupied. A VRF system will transfer heat from overheated rooms to underheated rooms automatically using refrigerant flow—saving compressor work. Classrooms transition from fully occupied to minimally occupied quite quickly (for example, at the end of the day when children leave, but teachers may stay to do more work). Due to the individualized controls and the inverter-driven compressors, fans, and expansion valves, the VRF systems can quickly ramp up or down in response to the changing internal loads without requiring any action or attention from the teacher.

Integrating Ground Water Heat Exchange with Domestic Water Provision

According to Principal Driscoll and Ms. Chang, the school's well currently does not produce water acceptable for drinking due to the presence of arsenic and *e. coli* bacteria. We did not see the lab reports and do not have information about concentrations or other contaminants. Our expertise is not in water quality or water purification. The discussion in this section is only intended to flag ideas and potential synergies between a well-water geoexchange heat pump using the existing well, and water purification technologies.

The first observation is that the largest single use of water in the school is for toilet flushing, which does not require purified water. Given that any water purification system will be less expensive to install and use less energy to operate, it makes sense to separate the water systems into potable and non-potable systems. The co-location of both bathrooms and the physical proximity of all of the toilets to each other suggests that it should be a reasonably inexpensive and simple to disconnect the toilets and urinals from the main water supply and connect them to the non-potable water system. If un-treated water quality allows, the hand-washing sinks could also be on the non-potable system.

The potable water system could then be connected to the kitchen and drinking fountains. The water treatment system for this much smaller segment would be significantly smaller and less expensive than one designed to satisfy the full water demand of the school.

The water system with its pressure tanks has a highly variable demand profile. A properly designed geo-exchange water pumping system has a demand profile that follows space conditioning demand. This means that the pump required to satisfy heating demand at peak demand (which, by definition, only occurs in 2% of the hours per year) is almost never running at full capacity. Pumps driven by an Electrically Commutated Motor (ECM) can constantly adjust speed (and power consumption) in response to demand. A single ECM pump, sized for the geoexchange heat pump would be able to also supply the potable and non-potable systems with small compressor pumps attached to the pressure tanks both potable and non-potable sytems. This would allow the expense of the pump to be shared between both projects (or funded by whichever project acquired grant funding).

In discussion, Ms. Chang mentioned reverse osmosis. We think this might not be the best choice in this case. It requires a large quantity of water to be pumped. Depnding on the arsenic species present, it may not work. Reverse osmosis cannot remove arsenite (As (III)), so it must first be oxidized to arsenate (AS(V)). Some possible water treatment technologies to consider might include pre-filtration through a bio-sand filter, ozone injection to kill bacteria and oxidize arsenic which would then be removed through a coagulation agent like Ferric Sulphate, though it could also be done with reverse osmosis at this phase.

Summary

Gill Elementary school could be transformed from the town's largest energy users to one of the lowest, and become a high performing building with the potential to be powered entirely by renewable energy. To do this we recommend retrofitting the exterior walls and curtain wall panels with insulation, installing an air barrier at the ceiling, and replacing the outdated heating and ventilation systems with efficient and responsive heat recovery ventilation and heat pumps. These measures could reduce annual energy use for heating by 86% overall, and produce annual financial savings (including APS revenue) of about $17,000. The overall breakeven point for these investments would be just over seven years.

	Site energy savings (MMbtu)	Operating cost Savings	Implementation Cost	payback period (years)
wall insulation	298	$ 6,213	$ 33,660	5
panel insulation	46	$ 957	$ 3,821	4
Air barrier	117	$ 2,781	$ 27,359	10
Ventilation	117	$ 3,881	$ 17,000	4
*GSHP**	239	$ 9,241	$ 43,183	5
Whole system*	**770**	**$ 17,473**	**$ 125,023**	**7**

** Assumes envelope and ventilation measures are installed. Savings for envelope and ventilation measures assume existing boiler efficiency and oil prices. Savings for GSHP and whole system use GSHP efficiency and electricity prices to calculate savings.*

Next Steps

The municipality can contact CEE to schedule a call to discuss these findings and next steps (413-545-8510, energyextension@umass.edu)**.** A number of the recommended energy conservation measures and retrofits may be eligible for funding through state incentive programs. Consult with your utility company to find out about eligibility for Mass Save incentives or rebates for energy efficiency measures. As a Green Community, Gill is also eligible for grants from the Massachusetts Department of Energy Resources (DOER) through the Green Communities program to help fund energy efficiency projects. For more information, see http://www.mass.gov/eea/energy-utilities-clean-tech/green-communities/.

In addition, the Massachusetts Clean Energy Center's (MassCEC) Clean Heating and Cooling programs offer rebates to support the installation of renewable heating, hot water, and cooling technologies at facilities across the Commonwealth. These technologies are generally more cost-effective to operate than traditional fossil-fuel systems and can reduce greenhouse gas emissions, while maintaining a high level of comfort, automatic operations, and reliability. MassCEC provides substantial rebates toward implementation of clean heating and cooling systems. Find more information on the programs and technologies at http://www.masscec.com/government-non-profit/clean-heating-and-cooling.

References

1. Haverinen-Shaughnessy, U. & Shaughnessy, R. J. Effects of Classroom Ventilation Rate and Temperature on Students' Test Scores. *PLOS ONE* **10**, e0136165 (2015).

2. Vincent, D., Annesi, I., Festy, B. & Lambrozo, J. Ventilation system, indoor air quality, and health outcomes in Parisian modern office workers. *Environ. Res.* **75**, 100-112 (1997).

3. Schaffer, M. E. ANSI Standard: Complying With Background Noise Limits; *ASHRAE Journal* **45**, 26-27 (2003).

4. Nelson, P. B. Sound in the Classroom: Why Children Need Quiet; *ASHRAE Journal* **45**, 22-28 (2003).