Underground Garage in Multifamily Housing—
getting a handle on life cycle cost

WILLIAM WEBER
OUTCOME SUMMARY

Workshop Participants:

Inquiry Team: Dale Forsberg, Watson-Forsberg (cost estimating); Adam Niederloh and Luke Hollenkamp, The Weidt Group (energy modeling); and William Weber (CSBR – coordination and facilitation)

Overview

The Center for Sustainable Building Research (CSBR) in conjunction with Minnesota Green Communities held a workshop in November of 2014 to explore the impact of energy and cost associated with underground garages in multifamily housing apartment buildings. The work hoped to address the large impact garages have on both first cost and life cycle cost, which as buildings become more efficient accounts for an increasing larger percentage of total building utility cost. The goal of this work is to understand and propose solutions to create energy efficient garages, and suggest alternatives new construction projects in cold climate that are having difficulty meeting EnergyStar requirements. This is primarily due to the requirement for unheated garages and plenum spaces. Concerns stemming from these mandates are pipe freeze, surface icing, safety, and market perception. The work considered technical solutions examining both alternative design solutions (design for smaller loads), and alternative mechanical solutions (efficiency).

Summary

The workshop led to three avenues of inquiry exploring; (1) alternatives parking configurations; (2) alternative designs for unheated garages; and (3) alternative mechanical systems to achieve deep energy savings. A discussion of each exploration follows below. The summary recommendations stemming from the explorations include the following:

First Tier

- Eliminate snow melt systems whenever possible (16% total building energy savings)
- Carbon Monoxide (CO) sensor control of garage ventilation fans (80% savings for garage energy)
- Occupancy controlled LED lighting (79% savings for garage lighting)
- Right size parking (energy cost for a code based garage are $400/stall)
- Insulate the common garage ceiling and first floor to meet ASHREA 55 standards
- Reduce set points 5F to 40F (10% savings for garage energy)

Upcoming changes to the code will mandate carbon monoxide (CO) sensor control of ventilation, dual level lighting fixtures with occupancy sensors in most spaces, and a slight decrease in lighting power allowances.

While achieving significant energy savings these measures do not necessarily result in an EnergyStar qualifying design. EnergyStar allows heat tape in unheated garages to avoid pipe freeze, and a conservative snowmelt system to avoid icing. At this juncture not enough is known about the performance of this design to understand the real world implications of these design changes.
Energy Overview

The Weidt Group provided general energy use patterns for a code based building at the workshop. The information presented underscored the need for energy conservation measures in underground garages in multifamily residential buildings. Energy cost of ventilating and conditioning garages actions for 27% of energy expenditures in a code based building. Two primary drivers of energy in garages are easily identifiable (figure 1). Snowmelt systems account for 34% of garage energy cost (36% of energy use) and heating due primarily to ventilation 52% of cost (69% of energy use). These two major energy users were the primary focus of energy reduction strategy exploration.

Summary of base building for energy and cost modeling is the following:
43,800 sf residential building (total building includes garage sf)
11,800 sf garage
31 apartment units; 39 bedrooms
34 parking spots
The baseline analysis assumes an indoor garage, with an outdoor ramp leading to it with a snowmelt system of 3,500 sf.
Evaluation Criteria
The evaluation criteria of alternative options was generated during the workshop. The primary quantitative measures are energy use, energy cost, first cost, life cycle cost and payback. Qualitative assessment and impact was also considered. Criteria scenarios varied based on relevance and were subjectively evaluated on a relative scale. Below is a list of qualitative assessment points not all of which were used in the evaluation process, but could be useful for further discussion and consideration.

Outcome Measures
Energy Cost ($)
Energy Use (EUI)
Energy Savings ($/EUI)
First Cost
Life cycle cost
Simple Payback
Annual net loss rents ($)
Site density
Energy Star

Risk Assessment
Failure Assessment
Indoor Environmental Quality
Thermal comfort adj. units

Maintenance
Pipe Freeze
Operations Considerations
Replacement costs
Ease of replacement | Access to systems

Livability Factors
Neighborhood walkability
Bike access and storage
Marketability
Ease of access to garage/basement
Safety (slip and fall)
Safety (personal)
Recycling/trash access

In addition to the evaluation criteria, garage design variables were also outlined during the workshop. A list for reference is below. Not trait variables were explored as part of the project.

Garage Traits
Ventilation Type (mechanical and natural)
Ramp location
Temperature control
Snowmelt | Icing Control
Net loss of units (est.)
Cubic volume
Envelope area
Surface Area
CO Control
Freeze protection (pipes)
Garage door area
Alternative Garage Configurations

Multiple options for alternative configurations for parking were considered and evaluated against both quantitative and qualitative criteria. This investigation focused on site scale options ranging from surface parking to underground garage parking; and includes alternative configurations for in building parking options such as garden level parking and parking access ramp location (see figure xx). All scenarios included 34 parking spaces, indoor parking area was 11,800 sf. Surface parking, structured parking, and garden level parking are naturally ventilated. Energy consumption is due to lighting loads only. Below grade indoor parking includes code based ventilation, heating, lighting and where noted energy attributed to ramp snowmelt system.

<table>
<thead>
<tr>
<th>Description</th>
<th>Ramp Location</th>
<th>Mechanical Ventilation</th>
<th>Snowmelt Location</th>
<th>Annual Energy Cost</th>
<th>First Cost</th>
<th>30 Year Cost</th>
<th>10% Year Cost</th>
<th>30 Year Net Loss of Rent (50%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPT 1 Surface Parking</td>
<td>n/a</td>
<td>n</td>
<td>n</td>
<td>$ 1,672</td>
<td>$ 98,600</td>
<td>$ 348,480</td>
<td>$ 497,240</td>
<td>$ -</td>
</tr>
<tr>
<td>OPT 2 Structured Parking</td>
<td>n/a</td>
<td>n</td>
<td>n</td>
<td>$ 1,672</td>
<td>$ 646,000</td>
<td>$ 348,480</td>
<td>$ 1,044,640</td>
<td>$ -</td>
</tr>
<tr>
<td>OPT 3a Garage Parking - basement level</td>
<td>ext.</td>
<td>y</td>
<td>y</td>
<td>$ 20,823</td>
<td>$ 697,000</td>
<td>-</td>
<td>$ 1,321,690</td>
<td></td>
</tr>
<tr>
<td>OPT 4a Garage Parking - basement level</td>
<td>int.</td>
<td>y</td>
<td>n</td>
<td>$ 13,745</td>
<td>$ 660,000</td>
<td>-</td>
<td>$ 1,072,350</td>
<td></td>
</tr>
<tr>
<td>OPT 5 Garage Parking - Garden Level</td>
<td>n/a</td>
<td>n</td>
<td>n</td>
<td>$ 1,672</td>
<td>$ 578,000</td>
<td>-</td>
<td>$ 628,160</td>
<td></td>
</tr>
</tbody>
</table>

Figure xx: Alternative parking scenarios, first cost and 30 year cost.

Focusing on 30 year cost (first cost, 30 year energy cost, and additional cost, excludes maintenance cost) the surface parking lot is the least expensive parking option, followed by the garden level parking option. Ongoing energy cost for these options are attributable to lighting. This analysis for the surface lot and the structured parking used $20/sf for land cost. Land cost can have a dramatic impact on project feasibility and may be cost prohibitive when taken in context of the overall project budget.

The current standard practice of underground parking with exterior heated ramp for snowmelt is the most expensive option. Expanding cost consideration to potential loss of revenue shifts the outcome, making the underground garage with indoor ramp the highest cost option. Loss of revenue was expressed as a potential concern by developers when the parking access ramp is moved indoors as a strategy to eliminate snowmelt systems. This cost noted in the last column of figure xx, is highly variable and could be overcome in part by altering the design of the building to minimize disruption of floor plans.

A discussion of the qualitative criteria is necessary to understand the impact parking configuration has on the aspects of the development including impacts on urban character, density, safety and livability. A relative and subject scale was applied to the criteria shown Figure xx. The color coded scale is from green to red, with green being the better and red being worse.
Overall the criteria show standard practice ranks higher in most areas. Parking outside of the building, or in a garden level open parking configuration meet EnergyStar requirements. Surface parking and stand-alone structured parking rank lowest and have negative impacts including decrease in density, disruption of the urban fabric, and increased safety concerns (slip and fall, and personal security). The garden level parking mitigates many of these factors. Bike storage is also potentially impacted by moving parking outdoors. Maintenance factors to be considered are an increase in plowing and de-icing for the surface lot, structure parking and all options with outdoor ramps without snow melt.

All parking configurations could be design to meet EnergyStar. This would decrease energy cost overall. However, it increases pipe freeze risk and personal safety risk (slip and fall) bring all options on par regarding these issues. There is little data on actual operation of EnergyStar certified residential garages in cold climate. More information is need to understand the impact of the rules on garage performance.

**Alternative Designs for Unheated Garages**

Three options for alternative construction for parking were considered and evaluated. During the workshop several groups explored options rethinking the first floor assembly to expand the conditioned space or create an insulated space to house plumbing and waste pipes (figure xx). This is considered an alternative to heated plenums, which are disallowed by EnergyStar. All options would meet EnergyStar requirements with the exception of the base case, which represents current practice for heated underground parking garages. All scenarios included 34 parking spaces indoor parking area was 11,800 sf, energy estimates exclude snowmelt systems.

Option 1 utilizes standard construction (precast construction and gypcrete). Option 2 is an insulated open web wood truss system (wood joists, gypcrete, and insulation). Option 3 is a raised floor system (precast construction, wood joists, gypcrete and fire protection in the void space). Cost estimates for the all options are for primary costs of the specific system. Secondary cost due to design changes were not considered. The raised floor construction dramatically raises first cost which are not recouped through
energy savings. Cost for the all other options are comparable. Option 2 wood trusses has comparable cost to standard practice, but would limit building height due to code limitations.

Consideration regarding construction changes on operations is shown in figure xx (below). Accessibility of systems is more difficult in both the wood truss construction and the raised floor construction. This will likely lead to higher costs for replacement and maintenance. Consideration in design to clean-outs and traps would help to minimize maintenance costs. Unheated garages may lead to greater risk of slip and fall, however data could not be found to confirm or combat this concern. Marketability is impacted due to unheated garages in a market where heat garages has become the norm.

The floor temperature in apartments above unheated garages is a concern. Increases in insulation appear to have little impact on energy of first floor apartments, however low floor temperatures may result in residents turning up their thermostats to compensate. ASHREA 55 sets a floor surface temperature of 66.2F for thermal comfort. Modeling done using THERM (LBNL) demonstrates the
impact of insulation and the impact of thermal bridging on surface temperatures. Figures xx and xx contrast a fully insulated floor system to a partially insulated assembly. The full insulated system maintains an acceptable temperature. The partially insulated assembly does not.

Figure xx: Precast construction with hollow core blank, gypcrete, and 3 inches of spray applied insulation on plank with an uninsulated beam (R-14.8). Floor temperature range from 62.3F to 66.9F.

Figure xx: Precast construction with hollow core blank, gypcrete, and 3 inches of spray applied insulation on plank beam (R-20.2). Floor temperature 66.9F.

**Alternative Mechanical Systems to Achieve Deep Energy Savings**

Ideas for alternative mechanical solutions to achieve deep energy reduction in garages were generated during the workshop. Efforts focused on the primary energy drivers in garage spaces heating, ventilation and lighting. Discussion of the always on aspect of the garage program, but not always occupied lead to dynamic control of systems and demand response sensor controls. This exploration crossed system type and included both lighting and ventilation.

Utilizing energy modeling from The Weidt Group and cost information provided by Watson-Forsberg energy reduction, energy cost savings and simple payback was calculated for single strategies (figure xx) and bundles of strategies (figure xx). Looking at single strategies carbon monoxide sensor control of garage ventilation systems was the clear leader providing substantial savings 25.5 kBtu/sf per year,
$8,749 per year and a short payback period of less than a year. Coupling this system with heat recovery did not dramatically improve savings, and was substantially more expensive. The simplest system increased savings by $158 annually, and pushed the payback to 6.7 years. Increasing the efficiency level of the heating make-up units was less cost effective as a stand-alone measure than the sensor controlled ventilation. Reducing the heating set point by 5 degrees from 45F to 40F saves $1,205 annually.

Individual lighting strategy analysis demonstrates that sensor control has a strong impact on savings up to $448 per year demanding on the type of control. Lowering lighting power densities (LPD) and shifting to LED lighting results in meaningful savings. Calculation of paybacks is complicated for individual strategies due to the cost data format.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Heat</th>
<th>Fan/ Pump</th>
<th>Lights</th>
<th>Total kBtu/sf</th>
<th>Energy $/yr</th>
<th>Annual Savings</th>
<th>Incremental Cost</th>
<th>Simple Payback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulate floor/ceiling</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>$74,789</td>
<td>$36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garage occupancy sensor control</td>
<td>-0.3</td>
<td>0</td>
<td>0.6</td>
<td>0.4</td>
<td>$74,377</td>
<td>$448</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garage occupancy sensor control to 70% level</td>
<td>0</td>
<td>0</td>
<td>0.2</td>
<td>0.1</td>
<td>$74,680</td>
<td>$145</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garage LPD 25% lower than 90.1-2004</td>
<td>-0.2</td>
<td>0</td>
<td>0.4</td>
<td>0.2</td>
<td>$74,508</td>
<td>$317</td>
<td>$2,594</td>
<td>8.2</td>
</tr>
<tr>
<td>Garage LPD 65% lower than 90.1-2004</td>
<td>-0.4</td>
<td>0</td>
<td>1.0</td>
<td>0.7</td>
<td>$73,989</td>
<td>$836</td>
<td>$7,666</td>
<td>9.2</td>
</tr>
<tr>
<td>Garage makeup units at 83% efficiency</td>
<td>1.1</td>
<td>0</td>
<td>0</td>
<td>1.1</td>
<td>$74,458</td>
<td>$367</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Garage makeup units at 91% efficiency</td>
<td>3.6</td>
<td>0</td>
<td>0</td>
<td>3.6</td>
<td>$73,593</td>
<td>$1,232</td>
<td>$8,000</td>
<td>6.5</td>
</tr>
<tr>
<td>Garage makeup units at 95% efficiency</td>
<td>4.7</td>
<td>0</td>
<td>0</td>
<td>4.7</td>
<td>$73,218</td>
<td>$1,607</td>
<td>$15,000</td>
<td>9.3</td>
</tr>
<tr>
<td>Carbon monoxide sensor control of garage vent fans</td>
<td>25.5</td>
<td>0.3</td>
<td>0</td>
<td>25.7</td>
<td>$66,076</td>
<td>$8,749</td>
<td>$5,000</td>
<td>0.6</td>
</tr>
<tr>
<td>Garage run-around heat recovery w/ CO control</td>
<td>27.8</td>
<td>0.2</td>
<td>0</td>
<td>27.9</td>
<td>$65,918</td>
<td>$8,907</td>
<td>$65,000</td>
<td>6.7</td>
</tr>
<tr>
<td>Garage sensible heat recovery w/ CO control</td>
<td>28.9</td>
<td>0.2</td>
<td>0</td>
<td>29.0</td>
<td>$65,050</td>
<td>$9,775</td>
<td>$155,000</td>
<td>15.3</td>
</tr>
<tr>
<td>Reduced heating setpoint</td>
<td>3.5</td>
<td>0</td>
<td>0</td>
<td>3.5</td>
<td>$73,620</td>
<td>$1,205</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Reduced infiltration</td>
<td>0.4</td>
<td>0</td>
<td>0</td>
<td>0.4</td>
<td>$74,702</td>
<td>$123</td>
<td>-</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure xx: Energy Modeling Strategy energy reduction, cost savings, incremental cost and simple payback.

Strategy bundles were created in order to assess the combined impact of individual strategies. The bundles are outlined in figure xx, and the results in figure xx. Three bundles were created and compared to the code base model. The scope of energy savings strategies increase by bundle. For example Bundle 1 is limited to three primary strategies, while Bundle 3 has five.

Interaction between energy savings strategies results in energy reduction and cost savings less than the sum of the individual strategies. This is typical. The primary interaction noted in looking at the combined savings for garage is ventilation and heating. Carbon monoxide sensor controlled ventilation significantly reduces air exchange and thus nullifies much of the energy savings attributable to increased boiler efficiencies.

Bundle 2 has the shortest payback of 1.5 years and an annual savings of $10,140. It combines many low cost high impact strategies and relies on demand controls to achieve savings. This bundle includes carbon monoxide sensor controlled ventilation, 70% sensor controlled lighting, advanced LED lighting package, and improved heater efficiencies.

Bundle 3 has the longest payback at 14.8 years and an annual savings of $12,068. It combines all top of the line performing strategies. It combines demand control sensors with maximum mechanical
strategies

<table>
<thead>
<tr>
<th>Baseline; CODE1</th>
<th>Bundle 1; BND01</th>
<th>Bundle 2; BND02</th>
<th>Bundle 3; BND03</th>
<th>Bundle 3; Adjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Figure xx: Energy Modeling Bundle Strategies

<table>
<thead>
<tr>
<th>Totals for Building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Total KBtu/sf</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Baseline; CODE1</td>
</tr>
<tr>
<td>Bundle 1; BND01</td>
</tr>
<tr>
<td>Bundle 2; BND02</td>
</tr>
<tr>
<td>Bundle 3; BND03</td>
</tr>
<tr>
<td>Bundle 3; Adjusted</td>
</tr>
</tbody>
</table>

Figure xx: Energy Modeling Bundle Strategies

efficiency. This bundle includes carbon monoxide sensor controlled ventilation with sensible heat recovery, occupancy sensor controlled lighting, advanced LED lighting package, and the highest heater efficiencies. In addition in adjust the temperature set point down 5F, and assumes improved air sealing.
As noted above, sensible heat recovery is not a cost effective measure when combined with carbon monoxide controlled ventilation. Bundle 3 – Adjusted removes heat recovery to suggest the potential savings of the other high end factors explored in combination in Bundle 3. A separate energy model was run for this scenario, but savings from the strategy list attributable to sensible heat recovery were subtracted. Under this new scenario the simple payback drops to 2.6 years with annual cost savings of $11,042.

**Snowmelt System Elimination**

Serious consideration should be given in all future design to the elimination of the snowmelt system through ramp location and design. As noted previously snowmelt systems account for 34% of garage energy cost and 36% of garage energy use. Boiler equipment efficiency can reduce but not eliminate load. Prediction of energy use and energy use reduction is difficult to calculate due to the limits of energy modeling due to the number assumptions that must be made. Once a ramp is configured and built assuming a snowmelt system will be used, there is little that can be done to reduce the load over the life of the building that will not have an adverse effect on safety.

The following design considerations should be considered.

- Consider moving the ramp indoors
- Orient ramp to the south and use dark pigmented surfaces to allow for solar exposure and natural snowmelt
- Design ramps with slopes that do not require snowmelt (8% or less)
- Take advantage of site grade changes to limit garage depth, and therefore garage ramp grade and length
- Limit the number of ramps in an one development to spread the snowmelt load over a greater number of parking spaces

**Code Discussion**

Minnesota has recently adopted ASHREA 90.1- 2010, which has replaced ASHREA 90.1- 2004. Utilizing the energy modeling and strategy analysis is was possible to estimate the impact of the new code garage energy. Below, figure xx show whole building itemized energy use, and itemized energy use reduction attributable to the garage. Note this is an estimate based on strategy and bundle options and is not a whole building energy model demonstrating whole building energy savings from the code change. Modeling excludes modification of snowmelt systems. This exercise demonstrates the change in code will result in a reduction of garage energy use of 25.9 kBTU/sf/yr for the modeled building. This is a 75% reduction in garage energy use. The savings is primarily attributable to heating savings link to carbon monoxide sensor controlled mechanical ventilation.
### Table: Itemized estimated garage energy use reduction by code

<table>
<thead>
<tr>
<th>Itemized KBtu/sf</th>
<th>Baseline</th>
<th>CODE 90.1-2010</th>
<th>Itemized KBtu/sf Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>70.3</td>
<td>44.8</td>
<td>25.5</td>
</tr>
<tr>
<td>Cool</td>
<td>4.1</td>
<td>4.2</td>
<td>-0.1</td>
</tr>
<tr>
<td>Fan/ Pump</td>
<td>6.1</td>
<td>5.8</td>
<td>0.3</td>
</tr>
<tr>
<td>SWH</td>
<td>7.0</td>
<td>7.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Lights</td>
<td>7.1</td>
<td>6.9</td>
<td>0.2</td>
</tr>
<tr>
<td>Equip</td>
<td>25.7</td>
<td>25.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Total KBtu/sf</td>
<td>120.3</td>
<td>94.4</td>
<td>25.9</td>
</tr>
</tbody>
</table>

90.1-2010 requires space control with dual level fixtures as well as occupancy sensors in most spaces.  
90.1-2010 slightly reduces the interior lighting power allowance for most spaces (0.20 to 0.19).  
90.1-2010 requires energy recovery on more AHUs based on outdoor air volumes.

Figure xx: Itemized estimated garage energy use reduction by code. Baseline (ASHREA 90.1-2004) compared ASHREA 90.1-2010, excluding snowmelt systems.