## ANALYSIS 3: MECHANICAL REDESIGN

### Introduction

#### *Problem Statement*

The Palmerton has many different mechanical systems throughout the building. The commercial spaces each have their own air handling unit that provides the heating and cooling. Each apartment has its own heat pump for heating and cooling; additionally each bathroom has an additional electric wall heater for comfort. The corridors will also have their own cooling and heating system and the same is true with areas of the parking garage.

Operation costs have a greater potential to be reduced if some of these systems were combined and utilized energy recovery. This would allow for one larger piece of equipment rather than many smaller units. This could also decrease the time of installation, as long as the distribution does not have many further challenges.

In the current system all the fresh air comes directly from the outside and is heated or cooled then thrown into the space. This is then dumped back outside through the bathroom exhaust. This is a great deal of heat that may have the potential to be recovered.

#### *Goal*

Running a water loop through the building and allowing smaller water to air heat pumps that exchange heat with this loop, can allow for energy savings. The temperature of the water loop would be maintained from a roof top boiler and condenser. Additionally, allowing the fresh air and the stale air to exchange heat before they leave or enter the building, will allow for a great deal of savings in operation costs.

#### *Expected Outcomes*

This system will cost more upfront, but will provide significant energy savings, that will save the owner a great deal of money over time.

## Mechanical Design

The existing mechanical system is energy intensive, has a large upfront cost, and does not allow for energy recovery. It does allow for each apartment to have complete control of their system and it also is easy to fix. If one breaks it does not hinder the whole building and can be fixed separately.

### *Design Goals*

There were 3 main areas of improvement that were looked into. The first was controlling the temperature that the heat pumps are exchanging with, which will increase efficiency of the heat pump and potentially allow for a downsizing of the system. This also allows the absence of electric resistance heat, which would typically be on a great deal of the winter. In turn this has the potential for energy savings, such that a payback period could be in 5 – 10 years.

Secondly, the consolidation of heating and cooling can allow for the system to be downsized and be more cost effective by using a couple larger pieces of equipment instead of small equipment for each apartment.

Thirdly the consolidation of air is a big area to achieve energy savings. Allowing the fresh air to exchange heat and humidity with the exhaust air will allow the heat pumps to do less work and will only require running a fan which would be on anyways. This is a potential way to save a lot of energy without using much.

While thinking about potential ways to tackle these design goals, the budget, schedule, and how it fits with the building, meaning that the building would not have to be altered significantly in order to implement the new system. These 3 items are the controlling factors when deciding on a mechanical design.

### *Design Process*

During construction there was a point where there was just a large hole in the ground and there was a break in excavation to remove contaminated soil. This would be a perfect opportunity to implement a ground source heat pump, which would allow the mechanical system to have a constant temperature heat dump that does not require energy to keep the temperature constant. This sounds like a great option and it is, however payback periods for ground source heat pumps tend to be longer then 10years in many cases. The size of this building would require a large amount of piping in order to transfer heat with the ground properly.

Taking the idea of a ground source heat pump, there was a thought that maybe exchanging heat with the bottom slab of the parking garage could be an option. This slab does not have any insulation below it allowing heat to transfer with the ground through the slab. After further investigation, the volume of concrete and the heat transfer between the slab and the ground was not even close to large enough for this to. The slab would end up holding too much of the heat being transferred into or out of it.

### *Design*

After this, it was decided to simulate a ground source heat pump by using a condenser and boiler to maintain a water loop at a somewhat constant temperature. Then water to air heat pumps could then exchange heat with this loop instead of the outside air. This also has the advantage of apartments exchanging heat with each other. If one heat pump is cooling and one is heating they would essentially be transferring heat between each other through the water loop. This situation is likely to happen because of solar gain and potentially personal preference of room temperature.

Consolidating the air in the building to allow for heat exchange was the next challenge. It was recommended by several mechanical designers that it would be better to consolidate all the air to one location, the roof. This would require running large vertical shafts for fresh air and exhaust through the building. These may get to large to fit somewhere in the building. The easiest way to consolidate the ductwork would be to run it in the corridors. The problem with this is that it would lower the ceiling height to below 8' which is not acceptable. Running these on the inside of the apartments on the hallway side would be a pain because they run through a lot of walls and through many rooms. This is not ideal for construction, it would be better to keep it simple.

Therefore it would be better to run them similar to the way they are run currently and let each unit have its own energy recovery ventilator. Although this is not consolidating as much, as the original goal, it does allow for air to exchange heat. This allows for only minor changes when talking about construction. The exhaust ductwork from the existing design was tweaked to accommodate the new system. The supply ductwork is exactly the same, only the mechanical closet ductwork changes slightly. This allows the installation to be more flexible when looking at the schedule. The next trade could be working on the inside of the apartment while a mechanical contractor can finish up the closet, install the ERV, and run the necessary plumbing for the water loop.

An ERV will be added that will exchange the heat and humidity with the outside air and the exhaust. The other bonus about adding this system is that, if this is run continuously it can constantly pull air out of the bathrooms and supply fresh air to the living spaces, the fan from the ERV can replace the exhaust fans in the bathroom, which are $200 a piece. This will also allow the air temperature to remain above F, completely eliminating the need for electric resistance heat. This will also help reduce the load required by the heat pumps, in turn helping reduce the boiler and the condenser.

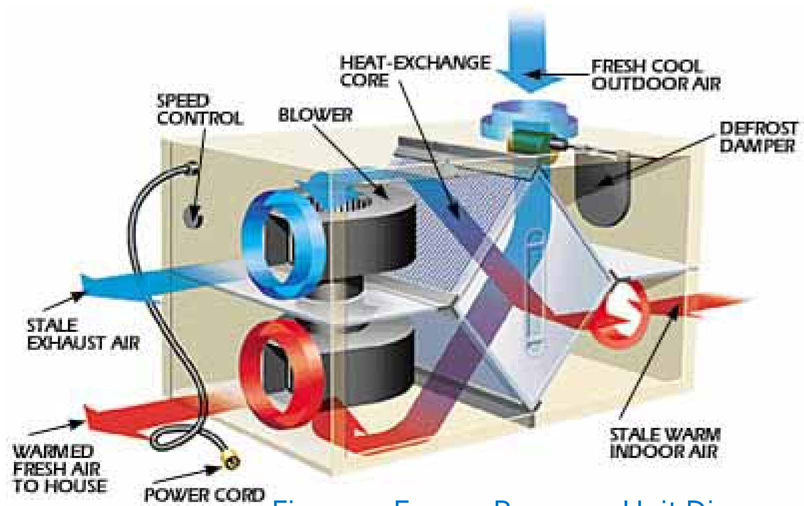


Figure 9: Energy Recovery Unit Diagram

### *Design Green Roof*

Due to the addition of the green roof, the three rooftop air handling units would need to be moved. Luckily there is some room to hide them in the parking garage. There is a space below and south of the commercial space that they could be put. The space shown in Figure 10 is tight but would be perfect place for distributing air throughout the commercial space. This can be constructed when trades are in the floors above. During this phase the parking garage will be used primarily for storage, leaving a great deal of it open to be get work done. The schedule will not be impacted what so ever. This is also ideal to run the water loop to them since they are right next to the mechanical closets.

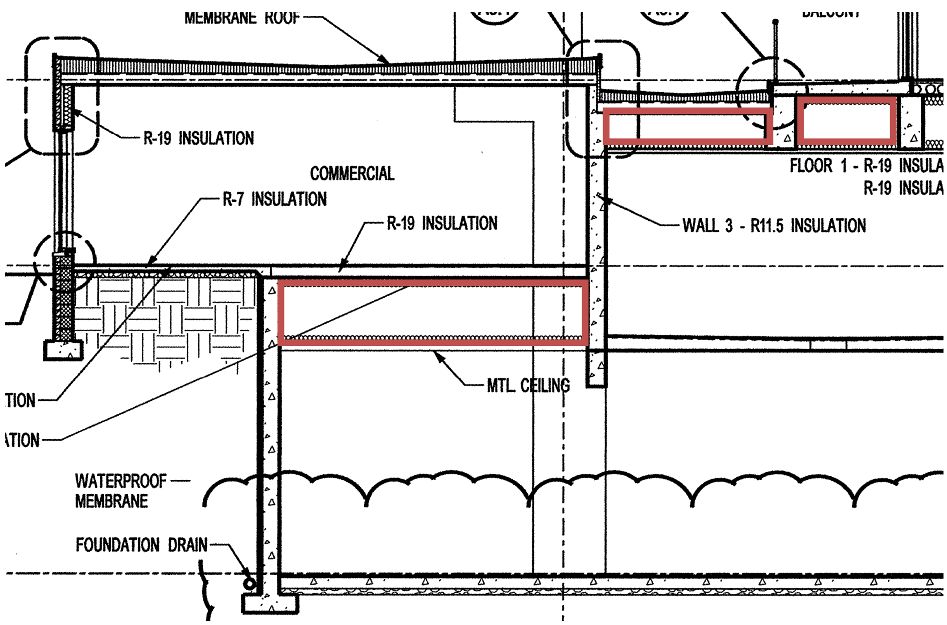


Figure 10: Commercial Mechanical Placement

**Mechanical Redesign, Breadth 2**

First the loads for the apartments were analyzed. See Appendix J: Mechanical Calculations, looking at the numbers boxed out this shows the heating and cooling demands by the space during peak months. Due to the implantation of the ERV while sizing this system the system does not need to be oversized to try to get those couple days that are too cold or warm. Also the heat pumps will always have a similar heat to exchange from due to water loop, which will be kept at 60°F and in the summer at 90°F. This allows the heat pump to be designed specifically for a max heat of 90°F not anything higher.

For the 2 bedroom apartment there is a heat loss of 14,405 Btu/hr and a heat gain of 17,288 Btu/hr. This means that the 2 bedroom heat pump can be downsized from a capacity of 24 MBH heating and 27 MBH cooling down to 14 MBH cooling and 18 MBH heating. This equates to a 2 ton unit instead of a 2.5 ton unit.

For a 1 bedroom apartment a heat loss of 11,159 Btu/hr and a heat gain of 11,006 Btu/hr. The existing heat pump was designed for 12,800 Btu/hr cooling and 16,600 Btu/hr heating. This heat pump could be downsized from a 1.5 ton to a 1 ton heat pump, but that will cut it extremely close. The heat pump on the extreme days might be straining to keep up. Therefore this heat pump will not be downsized.

### *Water Loop Heat Pumps*

Next the water to water heat pumps were selected. A Trane Axiom GEV 018 for the smaller apartments and a GEV 024 for the larger apartments. Refer to Appendix L: Trane Heat Pumps.

| | | |
|---|---|---|
| GEV 018 | 570 CFM | 4.2 GPM |
| Absorbed Heat into the Water Loop | 14.75 MBH | |
| Released Heat into the Water Loop | 25 MBH | |
| | | |
| GEV 024 | 750 CFM | 5.5 GPM |
| Absorbed Heat into the Water Loop | 20.3 MBH | |
| Released Heat into the Water Loop | 32.6 MBH | |

Boiler Size = 10*20.3 + 55*14.75 = 1,014 MBH

Condenser Size = (10*25 + 55*32.65) / 12 = 170.25 Tons

### *Water Loop Distribution Sizing*

Next the distribution piping system was designed for the apartments. The flow rates of all the heat pumps were added up and the piping was sized of the chart in Figure 11.

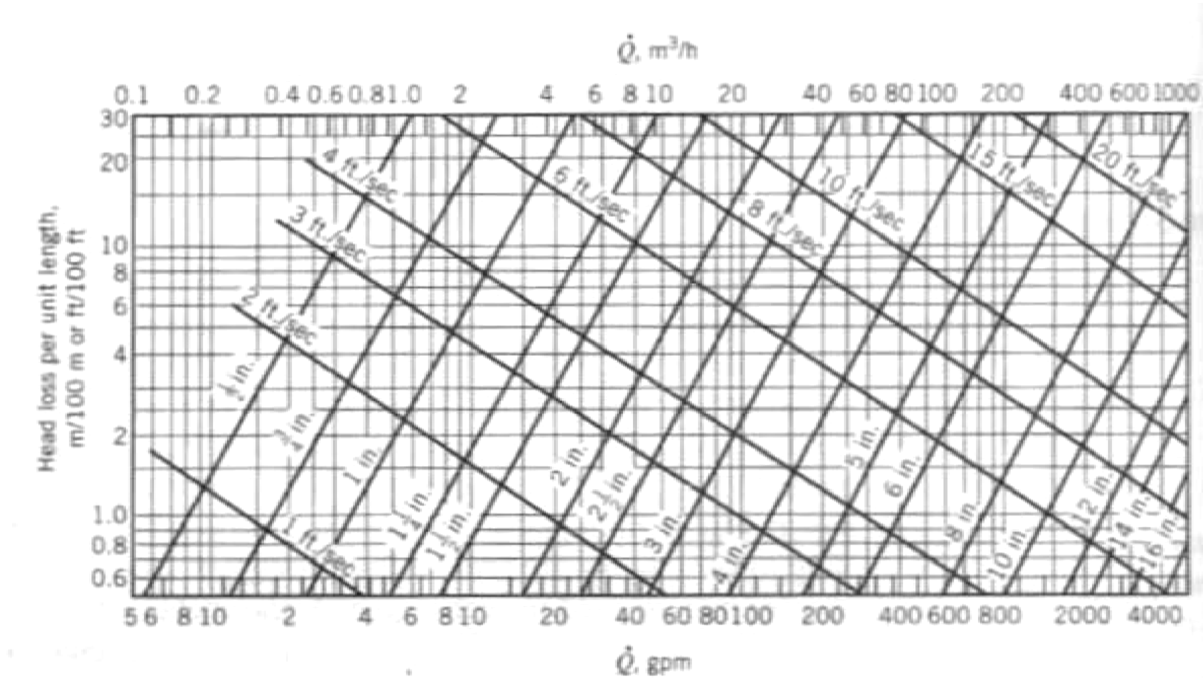


Figure 11: Friction Loss Due to Flow of Water in Steel Pipe (schedule 40)

| Table 6: Pipe Work Calculations | | | | | |
|---|---|---|---|---|---|
| 1 BR Shaft | | | 2 Bedroom Shaft | | |
| Story | Flow Rate | Size | Story | Flow Rate | Size |
| | | | 7 | 38.5 | 1.5 |
| 6 | 25.2 | 1.5 | 6 | 33 | 1.5 |
| 5 | 21 | 1.25 | 5 | 27.5 | 1.5 |
| 4 | 16.8 | 1.25 | 4 | 22 | 1.25 |
| 3 | 12.6 | 1 | 3 | 16.5 | 1.25 |
| 2 | 8.4 | 1 | 2 | 11 | 1 |
| 1 | 4.2 | 0.75 | 1 | 5.5 | 0.75 |

| Table 7: Pipe Quantities | | | | |
|---|---|---|---|---|
| Type | Quantity | Length for shafts | Length at roof | Total |
| 4 | | | 80 | 80 |
| 2.5 | | | 100 | 100 |
| 2 | | | 248 | 248 |
| 1.5 | 32 | 576 | 678 | 1254 |
| 1.25 | 16 | 288 | | 288 |
| 1 | 16 | 288 | | 288 |
| 0.75 | 12 | 216 | | 216 |

### *Energy Recovery Ventilator*

The ERV is sized based off of using the previous cfm from the existing unit 75 cfm. The ERV is only 70 cfm however this can just be run a little longer or the previous design was potentially oversized. Refer to Appendix K: EV70 Specifications.

### Mechanical Estimate

The estimate for the mechanical system shown in Table 8 shows the costs per apartment.

**Table 8: Mechanical Redesign ERV Estimate**

| Item | Size | Type | Unit | Labor Hours | Materials | Labor | Total | Tot. 2 BR | Total | Time | Tot. 1 BR | Total | Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Existing** | | | | | | | | | | | | | |
| Spiral | 6" | straight | LF | 0.057 | $ 1.76 | $ 2.17 | $ 3.93 | 72 | $ 280.00 | 4 | 30 | $ 117.90 | 1.71 |
| Ductwork | 6" | connector | Ea | 0.182 | $ 2.60 | $ 6.90 | $ 9.50 | 4 | $ 38.00 | 1 | 2 | $ 19.00 | 0.36 |
| | 6" | elbow | Ea | 0.364 | $ 5.75 | $ 13.80 | $ 19.55 | 4 | $ 78.20 | 1 | 2 | $ 39.10 | 0.73 |
| Brick Vent | 6" | | Ea | 0.333 | $ 25.00 | $ 14.05 | $ 39.05 | 2 | $ 78.10 | 1 | 1 | $ 39.05 | 0.33 |
| Exhaust fan | 130 | Nutone QT140L | Ea | 0.83 | $ 200.00 | $ 32.50 | $ 232.50 | 2 | $ 465.00 | 2 | 1 | $ 232.50 | 0.83 |
| Heat Pump | 2.5 | Air Source | Ea | 13.333 | $ 1,625.00 | $ 515.00 | $ 2,140.00 | 1 | $ 2,140.00 | 13 | 0 | $ - | 0.00 |
| Heat Pump | 1.5 | Air Source | Ea | 13.115 | $ 1,575.00 | $ 510.00 | $ 2,085.00 | 0 | $ - | 0 | 1 | $ 2,085.00 | 13.12 |
| **Total** | | | | | | | | | **$ 3,079.30** | **22** | | **$ 2,532.55** | **17.08** |
| **Total All Apts.** | | | | | | | | | **$ 169,361.50** | **1207** | | **$ 25,325.50** | **171** |
| **Proposed With ERV** | | | | | | | | | | | | | |
| Spiral | 6" | straight | LF | 0.057 | $ 1.76 | $ 2.17 | $ 3.93 | 66 | $ 260.00 | 4 | 42 | $ 165.06 | 2.39 |
| Ductwork | 6" | connector | Ea | 0.182 | $ 2.60 | $ 6.90 | $ 9.50 | 5 | $ 47.50 | 1 | 4 | $ 38.00 | 0.73 |
| | 6" | elbow | Ea | 0.364 | $ 5.75 | $ 13.80 | $ 19.55 | 2 | $ 39.10 | 1 | 3 | $ 58.65 | 1.09 |
| | 6" | tee | Ea | 0.533 | $ 8.20 | $ 20.00 | $ 28.20 | 1 | $ 28.20 | 1 | 0 | $ - | 0.00 |
| Flex Ductwork | 8" | non-insulated | LF | 0.08 | $ 2.20 | $ 3.03 | $ 5.23 | 24 | $ 125.52 | 2 | 8 | $ 41.84 | 0.64 |
| Can Light | | recessed | Ea | 0.4 | $ 77.50 | $ 16.80 | $ 94.30 | 2 | $ 188.60 | 1 | 1 | $ 94.30 | 0.40 |
| Heat Pump | 2 | Water Source | Ea | 9.412 | $ 1,300.00 | $ 365.00 | $ 1,665.00 | 1 | $ 1,665.00 | 9 | 0 | $ - | 0.00 |
| Heat Pump | 1.5 | Water Source | Ea | 10 | $ 1,375.00 | $ 390.00 | $ 1,765.00 | 0 | $ - | 0 | 1 | $ 1,765.00 | 10.00 |
| ERV | | Renewair 70 | Ea | 5 | $ 675.40 | $ 500.00 | $ 1,175.40 | 1 | $ 1,175.40 | 5 | 1 | $ 1,175.40 | 5.00 |
| **Total** | | | | | | | | | **$ 3,529.32** | **23** | | **$ 3,338.25** | **20.25** |
| **Total All Apts.** | | | | | | | | | **$ 194,112.60** | **1269** | | **$ 33,382.50** | **203** |

As seen the new system is more expensive however is able to make the previous system less expensive for multiple reasons. For the 2 bedroom apartments the ductwork for the bathroom was consolidated into one run straight to the ERV. Also the ERV is being used as the ventilation fan allowing the $200 Exhaust fans to be eliminated.

Working with Sound Geothermal Inc, calculations were performed, refer to Appendix K: EV70 Specifications, which show that the energy used by the heap pump will decrease and save $163.88 per year per smaller unit. Using a ratio to find out how much that equates to for the 2 ton heat pump $163.88 * 2/1.5 = $218.51 per year per larger heat pump. This equates to a 2 year pay back on the larger heat pump and a 5 year payback on the small heat pump. Overall it is a 2.4 year payback for designing the ERV into the apartments.

| Table 9: Mechanical Redesign Water Loop Estimate | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Proposed Water Loop | | | | | | | | | | | | |
| Piping | 0.75 | Schedule 40 | LF | 0.131 | $ 2.40 | $ 5.60 | $ 8.00 | 212 | $ 260.00 | 28 | | |
| | 1 | Schedule 40 | LF | 0.151 | $ 3.47 | $ 6.45 | $ 9.92 | 288 | $ 2,856.96 | 43 | | |
| | 1.25 | Schedule 40 | LF | 0.18 | $ 4.56 | $ 6.90 | $ 11.46 | 288 | $ 3,300.48 | 52 | | |
| | 1.5 | Schedule 40 | LF | 0.2 | $ 5.35 | $ 7.70 | $ 13.05 | 1254 | $ 16,364.70 | 251 | | |
| | 2 | Schedule 40 | LF | 0.25 | $ 7.10 | $ 9.60 | $ 16.70 | 248 | $ 4,141.60 | 62 | | |
| | 2.5 | Schedule 40 | LF | 0.32 | $ 11.00 | $ 12.30 | $ 23.30 | 100 | $ 2,330.00 | 32 | | |
| | 4 | Water Source | LF | 0.444 | $ 21.00 | $ 17.10 | $ 38.10 | 80 | $ 3,048.00 | 36 | | |
| Pump | 600 | | Ea | 14.118 | $ 3,150.00 | $ 340.00 | $ 3,490.00 | 1 | $ 3,490.00 | 14 | | |
| Boiler | 1275 | MBH | Ea | 80 | $ 10,300.00 | $ 3,275.00 | $ 13,575.00 | 1 | $ 13,575.00 | 80 | | |
| Cooling Tower | 167 | Tons | Ea | 32 | $ 25,900.00 | $ 1,275.00 | $ 27,175.00 | 1 | $ 27,175.00 | 32 | | |
| Total | | | | | | | | | $ 76,541.74 | 630 | | |
| Total with both systems | | | | | | | | | $ 304,036.84 | 2101 | $ 194,687.00 | 1378 |

Implementing the water loop is a larger investment then the ERV for several reasons. It requires a great amount of plumbing and 3 expensive pieces of equipment. It shows how expensive distribution can be. Everything installed in this system is completely addition and will not be able to help downsize the system. Potentially downsize the 1 bedroom apartment's heat pump; however it is still too close to call without fully modeling the entire system. The system costs an additional $76,541.74. Per apartment, that amounts to $1,177.57.

After talking to industry the ranges for how much energy this system would save, 8% - 12% were common numbers. Assuming this to be true and that an ERV is already installed, energy bills are now $621 a month for small apartments and then calculating based of a ratio of the size of the heat pump, the larger is $828 per month. The average yearly bill would be $796. 8% - 12% of that is equal to $63.38 to $95.52 saved per apartment per year. That means a 12.3 to an 18.5 year payback.

**Mechanical Schedule**

As seen in Table 8 the time to construct each is fairly similar meaning no change in the schedule. However when looking at the water loop, this is 630 man hours that is additional. With a crew of 4 this will take 4 weeks to accomplish. Refer to Appendix A1: Proposed Project Schedule.

**Summary**

The design behind the mechanical system is one such that it fits with the building the way it is designed and built, yet adds the owner value. This mechanical system will provide the owner with a good investment.

The first piece of the mechanical system that was implemented was an Energy Recovery Unit (ERV). This unit will run the outside fresh air past the exhaust air and exchanged the heat and the humidity between the two. This allows for less heating and cooling, hence saving energy. This was able to reduce the size of the heat pump in the 2 bedroom apartment from 2.5 tons - 2 tons. It also replaced the exhaust fans in all the apartments. Overall this system will cost more upfront but only $33,000 more, but will save about $200 a month. This will amount to a payback in 2.4 years.

The second system is a water loop that will run water throughout the building to all the heat pumps supplying 60°F to 90°F water. This water will be maintained by a 170 ton condenser and a 1,014 MBH boiler. Each apartment's heat pump will exchange heat with this water loop. There will be times where some apartments will be heating and some will be cooling. During this the heat pumps will be able to exchange heat with each other and the water loop will remain within the temperature range. Overall this system will cost an additional $76,500 giving a payback between 12.3 years to 18.5 years.