
Energy and Process Optimization Assessment at U.S. Army Installations in Germany

Keiserslautern Army Depot, Piermasens Army Depot, Katterbach Kaserne, Storck Barracks in Illesheim, and U.S. Army Garrison Wiesbaden Schools


September 2007

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Final Report

Approved for public release; distribution is unlimited.
Abstract: An energy and process optimization assessment (EPOA) study was conducted at selected U.S. Army installations in Germany and at two U.S. Army Garrison Wiesbaden schools to identify potential for energy conservation at those locations. The study identified energy conservation, process optimization, and environmental improvement opportunities that could significantly reduce operating costs and improve the installations’ mission readiness and competitive position. Eighty five energy conservation measures (ECMS) were identified, most of which were quantified economically; if implemented, these ECMS would reduce annual electrical energy consumption by approximately 2412 MWH, thermal heating consumption by 17277 MWH, and total operating costs by approximately $1.4 million/yr. Implementation of all these ECMS would cost approximately $9.7 million and would yield an average simple payback of 7.2 yrs. The study recommends that these potential cost savings be aggressively pursued with an program of energy and process optimization. A separate level I EPOA study of the industrial complex at the Germersheim DDDE and a Level II EPOA study at the flight simulator building in Illesheim were also recommended, since these locations both show potential for significant reductions in energy use and operating cost, and for improvement in worker productivity.
Executive Summary

Summary

An Energy and Process Optimization Assessment (EPOA) study was conducted at selected U.S. Army Installations, which included Keiserslautern Army Depot, Piermasens Army Depot, Katterbach Kaserne, Storck Barracks in Illesheim. Additionally, a brief assessment visits were made to the U.S. Army Germersheim Army Depot and a warehouse complex Big-O at Defense Distribution Depot Europe (DDDE), and at the U.S. Army Garrison Grafenwoehr to identify potential for energy conservation at those locations. A separate energy assessment analysis of two U.S. Army Garrison Wiesbaden Schools using energy concept adviser (ECA) developed by the IEA ECBCS Programme Annex 36 was performed at later time and its results are included in this report.

Eighty five Energy Conservation Measures (ECMs) addressing Central Energy Plants and distribution systems, Building envelopes, Compressed Air Systems, HVAC, Electrical and Lighting technologies were identified and most of them were quantified economically. If implemented, these ECMs would reduce annual electrical energy consumption by approximately 2412 MWh, thermal heating consumption by 17,277 MWh, and total operating costs (energy, maintenance and labor) by approximately $1.4 million/yr.

Implementation of these ECMs (Table E1) would cost approximately $9.7 million and would yield an average simple payback of 7.2 yrs. It is recommended that these potential cost savings be aggressively pursued with a program of energy and process optimization and that the 34 low cost/no risk measures be funded internally as soon as possible.

Implementation of 43 moderate cost/low risk ECMs with a higher investment requirements (between $20K and $1 million) will yield annual savings of $989,000, and will require $4.1 million in investments, which will yield a simple payback of 4.2 yrs. (Some of these complex ECMs may require SME support to provide 30 percent design.) These ECMs can be implemented either using central funding or third part financing mechanisms: Energy Savings Performance Contracts (ESPC) or Utility Energy Services Contracts (UESC).
The ECMs for the Wiesbaden Schools show a payback about 23 yrs; it is recommended that these ECMs be implemented when other retrofit non-energy related projects are planned, or by using ESPC or UESC mechanisms.

This study recommends a separate Level I EPOA assessment of the industrial complex at the Germersheim DDDE and a Level II EPOA assessment at the flight simulator building in Illesheim, since both those locations have a potential to significantly reduce energy use and operating costs, and to improve worker productivity.

The 72 ECMs at Keiserslautern and Pirmasens AD, summarized in Table E2, would reduce electrical consumption by approximately 2,386 MWh, thermal heating consumption by 11,594 MWh, total operating costs (energy, maintenance and labor) by approximately $1.1 million/yr; these ECMs would cost $3.85 million and would yield an average simple payback of 3.5 yrs.

The 11 primarily HVAC-related ECMs at Katterbach and Illesheim (described in Chapter 5 and summarized in Table E1) would reduce thermal heating consumption by 1,117 MWh and operating costs by approximately $74,500/yr, would cost $481000, and would yield an average simple payback of 6.5 yrs.

<table>
<thead>
<tr>
<th>Table E1. Summary of all ECMs.</th>
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<tbody>
<tr>
<td><strong>ECM Category</strong></td>
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<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Lighting - Kaiserslautern &amp; Pirmasens</td>
</tr>
<tr>
<td>Building Envelope - Kaiserslautern</td>
</tr>
<tr>
<td>Compressed Air - Kaiserslautern</td>
</tr>
<tr>
<td>Electrical - Kaiserslautern</td>
</tr>
<tr>
<td>HVAC - Kaiserslautern</td>
</tr>
<tr>
<td>Building Envelope - Pirmasens</td>
</tr>
<tr>
<td>District Heating - Pirmasens</td>
</tr>
<tr>
<td>Electrical Pirmasens</td>
</tr>
<tr>
<td>HVAC - Pirmasens</td>
</tr>
<tr>
<td>HVAC-Ansbach area: - Katterbach and Illesheim</td>
</tr>
<tr>
<td>Wiesbaden Schools</td>
</tr>
<tr>
<td>Total</td>
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</table>
Table E2. Summary of all ECMs at Keiserslautern and Pirmasens AD.

<table>
<thead>
<tr>
<th>ECM Category</th>
<th>Chapter</th>
<th># ECMs</th>
<th>Electrical Savings</th>
<th>Additional Savings</th>
<th>Total Savings</th>
<th>Investment</th>
<th>Simple Payback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting - Kaiserslautern &amp; Pirmasens</td>
<td>4.2</td>
<td>18</td>
<td>367</td>
<td>29.5</td>
<td>29.5</td>
<td>36.8</td>
<td>1.25</td>
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<tr>
<td>Building Envelope – Kaiserslautern</td>
<td>4.3</td>
<td>15</td>
<td>3,702</td>
<td>241</td>
<td>70</td>
<td>311</td>
<td>6</td>
</tr>
<tr>
<td>Compressed Air – Kaiserslautern</td>
<td>4.4</td>
<td>1</td>
<td>203</td>
<td>16</td>
<td>16</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>Electrical – Kaiserslautern</td>
<td>4.5</td>
<td>1</td>
<td>37</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
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<tr>
<td>HVAC – Kaiserslautern</td>
<td>4.6</td>
<td>26</td>
<td>1632.4</td>
<td>82.3</td>
<td>3734</td>
<td>475</td>
<td>1433.2</td>
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<tr>
<td>Building Envelope – Pirmasens</td>
<td>4.7</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>514</td>
<td>33</td>
<td>162</td>
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<tr>
<td>District Heating – Pirmasens</td>
<td>4.8</td>
<td>1</td>
<td>122</td>
<td>2</td>
<td>2,625</td>
<td>172</td>
<td>182</td>
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<tr>
<td>Electrical Pirmasens</td>
<td>4.9</td>
<td>1</td>
<td>25</td>
<td>2</td>
<td>1,019</td>
<td>48</td>
<td>48</td>
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<tr>
<td>HVAC – Pirmasens</td>
<td>4.10</td>
<td>5</td>
<td>122</td>
<td>10</td>
<td>1059</td>
<td>186.6</td>
<td>1099</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>72</strong></td>
<td><strong>2386</strong></td>
<td><strong>142.8</strong></td>
<td><strong>11,594</strong></td>
<td><strong>494</strong></td>
<td><strong>186.6</strong></td>
<td><strong>1099</strong></td>
</tr>
</tbody>
</table>

Energy conservation concepts developed for the two Wiesbaden Schools (described in Chapter 6 and summarized in Table E1) would reduce electrical consumption by approximately 25.8 Mwh, thermal heating consumption by 4565 MWh, and total operating costs by approximately $229,000/yr; these concepts would cost $5.4 million and yield an average simple payback of 23.4 yrs.

**Recommendations**

The Level I analysis of multiple complex systems conducted during the EPOA are not intended to be (nor should they be) precise. The quantity and quality of the systems improvement identified suggests that sufficient potential exists. It is recommended that these potential cost savings be aggressively pursued. It is also recommended that the low cost/no risk (so-called “slam dunk”) ECMs that can typically be implemented quickly (summarized in Table E3) be funded internally and implemented as soon as possible. All 34 ECMs in this table require an investment of $95K and would yield an average simple payback of about 0.8 yr. Together they have potential to save $118K/yr. All lighting projects under this category can be implemented as a one project.

Table E4 summarizes 43 moderate cost/low risk ECMs with a higher investment requirements (between $20K and $1 million). If implemented, these ECMs will together result in annual savings of $989 thousand, will require $4.1 million in investments, and will yield a simple payback of 4.2 yrs. (Some of these complex ECMs may require SME support to provide 30% design.) All projects which propose replacement of unit and other warm air heating systems with hydronic radiant panels are recommended to be packaged and implemented as a one project.
### Table E3. Summary of low-cost/no-risk ECMs.

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings</th>
<th>Thermal Savings</th>
<th>Total Savings</th>
<th>Investment $K</th>
<th>Simple Payback yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>LI1-LI18</td>
<td>Kaiserslautern and Pirmasens Lighting ECMs</td>
<td>367</td>
<td>0</td>
<td>29.5</td>
<td>36.8</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$9.7</td>
<td>0.63</td>
<td>0.63</td>
<td>2</td>
<td>3.2</td>
</tr>
<tr>
<td>BE6</td>
<td>Repair door seals, building 2226</td>
<td>51.8</td>
<td>3.4</td>
<td>7.2</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.7</td>
<td>0.6</td>
<td>0.6</td>
<td>1</td>
<td>1.6</td>
</tr>
<tr>
<td>BE9</td>
<td>Place insulated panel in unused door areas in building 2371</td>
<td>9.6</td>
<td>0.6</td>
<td>2</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>BE14</td>
<td>Repair door seals, building 2370</td>
<td>19</td>
<td>1.2</td>
<td>1.2</td>
<td>1.6</td>
<td>1.3</td>
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<tr>
<td></td>
<td>Close Opening Above Crane Using Brushes and Rubber Strips, Building 4000</td>
<td>10</td>
<td>0.6</td>
<td>0.6</td>
<td>1</td>
<td>1.6</td>
</tr>
<tr>
<td>BE18</td>
<td>Close Openings in Carpenter Storage Room, Building 4000</td>
<td>203</td>
<td>16.2</td>
<td>16.2</td>
<td>1.5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Switch off Computers When Not In Use -- Bldg 2233</td>
<td>36.8</td>
<td>2.9</td>
<td>2.9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Switch off Computers When Not In Use Building 4000</td>
<td>24.5</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HV4</td>
<td>Replace fans and Lengthen Duct on Heat Recovery Unit for Dynamometers 1 to 3</td>
<td>36.3</td>
<td>2.4</td>
<td>12</td>
<td>5.1</td>
<td></td>
</tr>
<tr>
<td>HV6</td>
<td>Reduce Excessive Air Use in Welding and Vehicle Exhaust Building 2233</td>
<td>46.4</td>
<td>3.7</td>
<td>7.5</td>
<td>2</td>
<td></td>
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<tr>
<td>HV13</td>
<td>Place Thermostat Controls Away From Occupants. Improved Control For Air Heaters</td>
<td>105</td>
<td>8.4</td>
<td>8.4</td>
<td>0.2</td>
<td>0.02</td>
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<tr>
<td>HV21</td>
<td>Have Heating Utility Turn off Heat to Buildings when not Warranted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Immediate</td>
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<tr>
<td>HV22</td>
<td>Use Heat from Generator Test for Building Heat, Building 2362</td>
<td>78</td>
<td>5.1</td>
<td>5.1</td>
<td>15</td>
<td>3</td>
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<tr>
<td>HV24</td>
<td>Provide Better Controls Of H&amp;V In Building 2371</td>
<td>365</td>
<td>29.2</td>
<td>29.2</td>
<td>0</td>
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<tr>
<td>HV25</td>
<td>Insulate Heating System Components-Building 2371</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt; 2 yrs</td>
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<tr>
<td>HV26</td>
<td>Provide Temperature Control Of Unit Heaters In Building 2281</td>
<td>0</td>
<td>180</td>
<td>11.7</td>
<td>7</td>
<td>0.8</td>
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<tr>
<td>Total 36ECMs</td>
<td></td>
<td>1147.7</td>
<td>91.9</td>
<td>1004.1</td>
<td>26.23</td>
<td>118.13</td>
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</tbody>
</table>

All moderate cost ECMs can be implemented either using central funding or third party financing mechanism (e.g., Energy Savings Performance Contracts [ESPC] or Utility Energy Services Contracts [UESC]). It is also recommended that the energy projects at Wiesbaden schools (WS-1 and WS-2) be implemented together with other planned retrofit non-energy related projects, or by using ESPC or UESC mechanisms.
Table E.4. Summary of moderate cost/low risk ECMs.

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings MWh/yr</th>
<th>$K/yr</th>
<th>Thermal Savings MWh/yr</th>
<th>$K/yr</th>
<th>Additional Savings $K/yr</th>
<th>Total Savings $K/yr</th>
<th>Investment $K</th>
<th>Simple Payback yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE1</td>
<td>Use transparent plastic panels behind glass sash, building 2233</td>
<td>2569</td>
<td>167</td>
<td>167</td>
<td>1052</td>
<td>6.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE2</td>
<td>a. Reduce solar heat load by use of conventional solar film OR</td>
<td>70</td>
<td>70</td>
<td>280</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
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<tr>
<td>BE3</td>
<td>Add vestibule on west side door of building 2223</td>
<td>137</td>
<td>8.9</td>
<td>8.9</td>
<td>105</td>
<td>11.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE5</td>
<td>Provide insulated panels for door openings in building 2222</td>
<td>28.3</td>
<td>1.84</td>
<td>1.84</td>
<td>16.8</td>
<td>9.1</td>
<td></td>
<td></td>
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<tr>
<td>BE7</td>
<td>Add vestibule on west side of building going-up ramp in building 2371</td>
<td>145</td>
<td>9.4</td>
<td>9.4</td>
<td>50.4</td>
<td>5.3</td>
<td></td>
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<tr>
<td>BE10</td>
<td>Insulate north wall blqg 2371</td>
<td>49.8</td>
<td>3.2</td>
<td>3.2</td>
<td>22.5</td>
<td>7</td>
<td></td>
<td></td>
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<tr>
<td>BE11</td>
<td>Use transparent plastic panels behind glass windows building 2281</td>
<td>158</td>
<td>10.3</td>
<td>10.3</td>
<td>64.7</td>
<td>6.3</td>
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<tr>
<td>BE12</td>
<td>Use transparent plastic panels to replace roof skylights building 2281</td>
<td>118</td>
<td>7.7</td>
<td>7.7</td>
<td>70.4</td>
<td>9.2</td>
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<tr>
<td>BE13</td>
<td>Repair and insulate roof building 2281</td>
<td>372</td>
<td>24.2</td>
<td>24.2</td>
<td>149.6</td>
<td>6.2</td>
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<tr>
<td>BE15</td>
<td>Insulate roof in maintenance building #2226</td>
<td>44.8</td>
<td>2.9</td>
<td>2.9</td>
<td>32.8</td>
<td>11.3</td>
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<td>BE16</td>
<td>Install Drop Ceiling in Certain Spaces, Building 4000</td>
<td>22</td>
<td>1.4</td>
<td>1.4</td>
<td>32.7</td>
<td>23.4</td>
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<td>BE19</td>
<td>Add Wall Insulation, Building 4171</td>
<td>464</td>
<td>30.2</td>
<td>30.2</td>
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<td>4.2</td>
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<td>HV2</td>
<td>Install Exhaust Fans To Ventilate Building 2233</td>
<td></td>
<td>116.64</td>
<td>116.6</td>
<td>65</td>
<td>0.6</td>
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<tr>
<td>HV3</td>
<td>Install Destraficati on Fans Recover Heat in Upper Strata – Building 2233</td>
<td>700</td>
<td>45.5</td>
<td>45.5</td>
<td>40</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HV5</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2233</td>
<td>6.06</td>
<td>98.5</td>
<td>98.5</td>
<td>459.9</td>
<td>4.7</td>
<td></td>
<td></td>
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<tr>
<td>HV7</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213</td>
<td>95</td>
<td>6.2</td>
<td>6.2</td>
<td>33.95</td>
<td>5.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV8</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213</td>
<td>24</td>
<td>15.6</td>
<td>15.6</td>
<td>97.9</td>
<td>6.3</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HV9</td>
<td>Recirculate Exhaust Air Back into Booth During Drying Operations, Building 2225</td>
<td>59</td>
<td>3.8</td>
<td>3.8</td>
<td>20</td>
<td>5.2</td>
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<tr>
<td>HV10</td>
<td>Replace heaters, insulate roof and improve usage of the heat exchange station in Warehouse, Building #2238</td>
<td>185.6</td>
<td>12.06</td>
<td>12.06</td>
<td>98.42</td>
<td>8.2</td>
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<tr>
<td>HV11</td>
<td>Replace heaters, insulate roof and improve usage of the heat exchange station in Warehouse, Building #2239</td>
<td>283.5</td>
<td>18.43</td>
<td>18.43</td>
<td>145.5</td>
<td>7.9</td>
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<td>HV14</td>
<td>Increase Ventilation to Reduce Solvent Fumes in Space-Building 2222</td>
<td></td>
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<td></td>
<td></td>
<td>40</td>
<td></td>
<td></td>
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<tr>
<td>HV15</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop Building 2225</td>
<td>76.5</td>
<td>4.4</td>
<td>4.4</td>
<td>31.75</td>
<td>7.2</td>
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<tr>
<td>HV16</td>
<td>Provide Heaters over Doors on South Side-Building 2226</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>HV17</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2226</td>
<td>120</td>
<td>7.8</td>
<td>7.8</td>
<td>54.5</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECM</td>
<td>ECM Description</td>
<td>Electrical Savings</td>
<td>Thermal Savings</td>
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<td>Total Savings</td>
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<td>Separate the Building Heating System from the Boiler and Connect the Building to</td>
<td>~25% ~25%</td>
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<td>Turn Off District Heating to Buildings in Summer</td>
<td>1019 47.9</td>
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<td>Improve HVAC System Controls Building 4000</td>
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Preface

This study was conducted for the Installation Management Agency Europe under Project Requisition No. 127396, Activity A1020, “Annex 46 Holistic Assessment Toolkit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo),” via Military Interdepartmental Purchase Request (MIPR) MIPR6CCERB1011. The technical monitor was David Yacoub, IMA Europe Region, Engineer Division.

The work was managed and executed by the Energy Branch (CF-E) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL principal investigators were Dr. Alexander Zhivov, John L. Vavrin, and David M. Underwood. Appreciation is owed to Dieter Geppert, Rudolf Gmelch, Helmut Wieder, Kenneth Holden, Ron Boese, Patrick Hutchins, Mark Love, Eric Wilking, Kent Carson, Paul Lindeman, Joseph Shultz, Guillermo Rivera, Ron Harris, Darius Nickolson, Franz Schwartz, Karl Kirch, and Peter Hartman. Major contributors to the study were Al Woody, Jim Newman, Erja Reinikainen, Manfred Klassek, Curt Bjork, Gunther Claus, Timo Husu, Michael Schmidt, Reijo Vaisanen, Martin Zinsser, and Timo Kauppinen. Dr. Thomas J. Hartranft is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Martin J. Savoie. The Director of CERL is Dr. Ilker Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Richard B. Jenkins, and the Director of ERDC is Dr. James R. Houston.
## Unit Conversion Factors

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1 Introduction

1.1 Background

An Energy and Process Optimization Assessment (EPOA) was conducted at several U.S. Army locations in Germany, which included Kaiserslautern Army Depot (KAD), Pirmasens Army Depot (PAD), Ansbach area (Katterbach Kaserne and Storck Barracks in Illesheim), and at the U.S. Army Garrison Wiesbaden Schools).

Kaiserslautern is 80 miles southwest of Frankfurt, Germany and 295 miles northeast of Paris, France. The Kaiserslautern Military Community is the largest military community outside the continental United States, and is a combined community consisting of Army and Air Force components. Several U.S. Army Europe, or USAREUR, installations are scattered throughout the KMC. The Army installations stretch from the east side of Kaiserslautern, west to Miesau and south to Pirmasens. There are eight different Army installations comprising the KMC: Kleber Kaserne (Northeastern Kaiserslautern) Daener Kaserne (Northeastern Kaiserslautern) Panzer Kaserne (Northeastern Kaiserslautern) Landstuhl Regional Medical Center (Landstuhl) Rhine Ordnance Barracks (Western Kaiserslautern) Pullaski Barracks (Western Kaiserslautern) U.S. Materiel Command Center Europe/226th Med Bn (remote site at Pirmasens) Vogelweh (Western Kaiserslautern). Kaiserslautern Army Depot has 191 buildings (total area of 2.8 million sq ft). Pirmasens has 73 buildings (1.1 million sq ft).

Pirmasens. The U.S. Army Medical Materiel Center, Europe (USAMMCE), in Pirmasens, Germany was established to deliver class VIII (medical material) to forces deployed to Camp Able Sentry, Macedonia, and, later, to Camp Bondsteel, Kosovo. USAMMCE had provided medical supply support indirectly to units deployed to Macedonia as part of the United Nations Protection Force since 1993. Since 1999 USAMMCE was tasked to establish a direct ground LOC to Camp Able Sentry for commercial and military trucks.

The Maintenance Activity – Pirmasens (MAP) has over 50 yrs experience in the repair and overhaul of electronic gear, shelter systems, heating and
air conditioning, power generation and selected automotive components for the U.S. Army, NATO, and other U.S. agencies.

Several Army installations in Ansbach include Shipton Kaserne, home to 6th Bn., 52nd Air Defense Artillery, Katterbach Kaserne, where the 1st Infantry Division's 4th Combat Aviation Brigade resides, Bismarck Kaserne where the post exchange, theater, and community club are located, and Barton Barracks, home to USAG Ansbach. Storck Barracks in Illesheim, located approximately 30 kilometers (18 miles) from Ansbach, are home to V Corps' 11th Aviation Regiment.

Elementary and the Middle School Hainerberg surveyed as a part of this project, are a part of the U.S. Army Garrison Wiesbaden, which includes Wiesbaden Army Airfield, Anderson Barracks in Dexheim and McCully Barracks in Wackernheim.

Wiesbaden Army Airfield serves as the headquarters installation for U.S. Army Garrison Wiesbaden, 1st Armored Division and 3rd Corps Support Command. Located 15 minutes away from Frankfurt International Airport, the Wiesbaden military community is host to several tenant units including the Corps of Engineers, Defense Logistics Agency, Wiesbaden Contracting Center, Army and Air Force Exchange Service, United Services Organization, Department of Defense Dependent Schools, Army Audit Agency, Defense Contract Management Command-Southern Europe, European Technical Center, Science and Technology Center and American Forces Network-Hessen. Anderson Barracks in Dexheim is located approximately 20 miles south of Wiesbaden Army Airfield and is the home of the 123rd Main Support Battalion, 1st Armored Division. McCully Barracks is home to the 501st Military Intelligence Battalion in Wackernheim.

1.2 Objectives

The objectives of this study were to identify energy inefficiencies and wastes at the selected U.S. Army Installations in Germany and propose energy related projects that could enable the installations to better meet the energy reduction requirements mandated by Executive Order 13423 and EPACT 2005.
1.3 Approach

This study was conducted by a team of government and private sector subject matter experts and researchers from the United States: Alexander Zhivov, David Underwood, and John Vavrin (CERL), Al Woody (Ventilation/Energy Applications, PLLC), Jim Newman (Newman Consulting Group, LLC), Finland: Erja Reinikainen (Granlund OY), Timo Kauppinen, VTT, Timo Husu, Motiva OY, Reijo Vaisanen (Fatman OY), Sweden: Curt Bjork (Curt Bjork Fastighet & Konsult AB) and Germany: Michael Schmidt, Martin, Zinsser, Manfred Klassek and Gunther Claus (University of Stuttgart, IGE), Heike Erhorn-Kluttig, Hans Erhorn and Anna Staudt (Fraunhofer IBP). The study was conducted using Energy Assessment Protocol developed by CERL in collaboration with a team of government, institutional, and private sector parties as a part of the IEA ECBCS Programme Annex 46 “Holistic Assessment Toolkit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo),” accessible through URL:


Energy Assessment of two schools in Wiesbaden was conducted using IEA Annex 36 Energy Concept Adviser, accessible through URL:

www.annex36.com

1.4 Scope

This Level I energy assessment evaluated warehouses and industrial production processes and buildings at Kaiserslautern AD and Pirmasens Army Depot, Wiesbaden Schools, and non-industrial facilities at the U.S. Army installations in Ansbach area (Katterbach and Illesheim): Barracks, Operations and Admin Facilities, Training Facilities, warehouses, motor pools, hangars, commissary, schools) and addressed areas related to the building envelope, ventilation, AC and heating systems, process ventilation, compressed air systems, energy plant and distribution systems, lighting, etc.

1.5 Mode of Technology Transfer

The results of this work will be presented to installations and IMCOM for their consideration in pursuing implementation and funding and for the follow-on Level II assessments in the identified areas. The results of this work are anticipated to contribute to an enhanced awareness within the
Installation Management Command (IMCOM), the U.S. Army Corps of Engineers and its districts, and other Army organizations of opportunities to improve the overall energy efficiency of Army installations. Plans are to disseminate this information through workshops, presentations, and professional industrial energy technology conferences. This report will also be made accessible through the World Wide Web (WWW) at URL:
http://www.cecер.army.mil
2 CERL’s Energy Assessment Methodology

2.1 The Energy Audit

A variety of energy and industrial assessment methodologies, protocols, and guidelines have been developed over the past years to improve energy efficiency of both private and government facilities. These audit tools have different emphasis and thoroughness, which depend on the audit objectives and on the available human and financial resources.

The study was conducted using Energy Assessment Protocol developed by CERL in collaboration with a team of government, institutional, and private sector parties as a part of the IEA ECBCS Programme Annex 46 “Holistic Assessment Toolkit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo).” The protocol is designed to assist installation energy managers and REMs to develop energy conservation projects (self-help for energy managers). With a group of American and international technical experts, ERDC/CERL has previously used this methodology for energy assessments conducted in 2003 – 2006 at Rock Island Arsenal, TYAD, SIAD and CCAD, Fort Carson, Fort Leonard Wood, Fort Stewart, Fort Myer, and Fort Polk.

The Energy Assessment Protocol addresses technical and non-technical organizational capabilities required to make a successful assessment geared to identifying energy and other operating costs reduction measures without adversely impacting Indoor Air Quality, product quality, or (in the case of repair facilities) safety and morale.

A critical element for energy assessment is a capability to apply a “holistic” approach to the energy sources and sinks in the audited target (installation, building, system, and their elements). The holistic approach suggested by the protocol includes the analysis of opportunities related to the energy generation process and distribution systems, building envelope, lighting, internal loads, HVAC, and other mechanical and energy systems. A useful way of visualizing the energy flows within a facility or process is the Sankey diagram, as shown in Figures 1 and 2.
Figure 1. Example Sankey diagram of energy usage, waste, and inefficiencies for an Army installation.

Figure 2. Example Sankey diagram of energy usage, waste, and inefficiencies for a building with production process.
The Protocol addresses several different scopes (building stock, individual building, system, and component) and levels of assessment. It distinguishes between the pre-assessment phase (Level 0: selection of objects for Energy Assessments and required composition of the audit team) and three levels of energy audits with differing degrees of rigor. Each of these three levels may be implemented in different ways: simplified or more detailed assessments, depending on the availability of energy consumption information and other data.

During the selection phase, one can choose from a building stock those facilities that have the most promising energy saving potential. Similarly, one can select from a specific building the systems to be audited or, from a system, the components to be considered for more detailed analysis. The scope and depth of the assessments differ in their objectives, methodologies, procedures, required instrumentation, and approximate duration (Figure 1).

A Level I audit (qualitative analysis) is a preliminary energy and process optimization opportunity analysis consisting primarily of a walk-through review to analyze and benchmark existing documents and consumption figures. The Level I audit takes from 2 to 5 days, and identifies the bottom-line dollar potential of energy conservation and process improvements.

No engineering measurements using test instrumentation are made. If the consumption figures are not available (e.g., due to the absence of metering), which is typical for many industrial facilities and manufacturing processes, the Level I audit can be based on analyses and estimates by experienced auditors. A Level I audit would normally recommend that the installation perform some metering, which could be followed by a Level II audit to verify the Level I assumptions, and to more fully develop the ideas from the Level I screening analysis.

A Level II audit (quantitative analysis) includes an analysis geared towards funds appropriation; this analysis uses calculated savings and partial instrumentation measurements with a cursory level of analysis. The Level II study typically takes 5 to 10 times the effort of a Level I, and could be accomplished over a 2- to 6-month period, depending on the scope of the effort.
The Level II effort includes an in-depth analysis in which the most crucial assumptions are verified. The end product will be a group of “appropriation grade” energy and process improvement projects for funding and implementation.

Finally, the Level III audit (continuous commissioning) is a detailed engineering analysis with implementation, performance measurement and verification (M&V) assessment, and fully instrumented diagnostic measurements (long term measurements). This level takes 3 to 18 months to accomplish. For ESPC projects, the Level III audit is prolonged until the end of the contract to guarantee that all installed systems and their components operate correctly over their useful lifetimes.

2.2 Keys to a Successful Audit

The key elements that guarantee success of the Energy Assessment are:

• Involvement of key facility personnel and their on-site contractors who know what the major problems are, where they are, and have already thought of many potential solutions;

• The facility personnel’s sense of “ownership” of the ideas that encourages a commitment to successful implementation; and

• A focus on site-specific, critical cost issues. If solved, the greatest possible economic contribution to a facility’s bottom line will be realized. Major potential cost issues can include: facility utilization (bottlenecks), mission, labor (productivity, planning and scheduling), energy (steam, electricity, compressed air), waste (air, water, solid, hazardous), equipment (outdated or state-of-the-art).

From a strictly cost perspective, process capacity and labor utilization/productivity and soldiers’ well-being can be far more significant than energy and environmental concerns. All of these issues, however, must be considered together to accomplish the facility’s mission in the most efficient and cost-effective way.

2.3 Requirements to an Energy and Process Auditing Team

Expertise in energy auditing is not an isolated set of skills, methods, or procedures; it requires a combination of skills and procedures from different fields. However, an energy and process audit requires a specific talent
for putting together existing ways and procedures to show the overall en-
ergy performance of a building and the processes it houses, and how the
energy performance of that building can be improved. A well grounded en-
ergy and process audit team should have expertise in the fields of heating,
ventilating, and air-conditioning (HVAC), structural engineering, electrical
and automation engineering and, of course, a good understanding of pro-
duction processes.

Most of the knowledge necessary for energy audit is a part of already exist-
ing expertise. Designers, consultants, contractors, and material and
equipment suppliers should be familiar with the energy performance of the specific field in which they are experts. Structural designers and con-
sultants should be familiar with heat losses through the building shell and what insulation should be added. Heating and ventilation engineers
should be familiar with the energy performance of heating, ventilation,
compressed air, and heat recovery systems. Designers of electrical systems
should know energy performance of different motors, VFD drives, and lighting systems. An industrial process and energy audit requires knowl-
edge of process engineers specialized in certain processes.

Critical to any energy and process audit team member is the ability to apply a “holistic” approach to the energy sources and sinks in the audited
target (installation, building, system, or their elements), and the ability to “step outside the box.” This ability presumes a thorough understanding of the processes performed in the audited building, and of the needs of the end users. For this reason, the end users themselves are important mem-
ers of the team. It is critical for management, production, operations and
maintenance (O&M) staff, energy managers, and on-site contractors to “buy-in” to the implementation by participating in the process, sharing
their knowledge and expertise, gathering information, and developing ideas.

2.4 Preliminary Data Collection

Data collection prior to going to site will save time and money, and will also foster a partnership between the energy assessment team and the end-users. Early collection of the following data is desirable:
- master plan, building drawings, information on different shop areas, volume, occupancy patterns, typical building/shop usage, process layouts
- production hours for different areas/shops, number of workers in each shift
- operation time for different processes
- any information on existing ventilation systems (layouts, airflows, controls, operation instructions)
- information on compressed air systems, boiler and chilled water plants, central child water and hot water/steam distribution systems
- heat and power prices (per unit)
- available information on energy use in recent years (electricity, oil, gas, etc.), site energy records of metered/sub-metered energy consumption, statistical data from the utility or/and bills, regarding electricity, oil, gas etc.
- total energy costs in recent years
- projected energy price increase (to be used in this project)
- key information related to production (number of units produced, use of raw materials, etc.) in different areas (past and the best estimates for the near and long-term future)
- recently completed energy improvement measures and results
- requirement to indoor air quality and thermal conditions in shops
- permits for exhaust air systems
- reports on recent studies (including ESCO proposals).
3 EPOA at Selected U.S. Army Installations in Germany

3.1 Project Planning and Schedule

Table 1 lists the assessment team and its organization. The energy audit took place over a 12-day period between Monday, 28 May and Thursday, 7 June 2006. Table 2 shows how the 12-day assessment process was organized by time, activities, and location to ensure that all of the critical areas in the scope of work were covered and that the process of the information collection, brainstorming sessions, and briefings to the management were built in to the busy personnel schedules. Table 2 lists sub teams assigned to the different process and energy system areas. In addition, An ERDC researcher made a brief assessment visits to the Germersheim Army Depot Complex Big-O at Defense Distribution Depot, Europe (DDDE) and to the U.S. Army Garrison Grafenwoehr (see Appendix A). In August 2006, a team from Fraunhofer Institute of Building Physics (Stuttgart) did a separate energy assessment analysis of two U.S. Army Garrison Wiesbaden schools using Energy Concept Advisor (ECA) software developed by International Energy Agency ECBCS Programme, Annex 36.

The formal out-briefing to the IMA Europe Region was conducted on 9 June 2006.

Table 1. Assessment team.

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<th>Kaiserslautern</th>
<th>Ansbach/Illisheim</th>
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<td>Al Woody</td>
<td>Timo Husu</td>
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<td>Jim Newman</td>
<td>Jim Newman</td>
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<td>Gunther Claus</td>
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<td>KAD</td>
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### Teams Assignments

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<td>(building number)</td>
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### Facilities, in no particular order

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<td>8007 (VMS)</td>
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### Table 2. Twelve-day assessment process.

#### Timeline

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#### 3.2 Energy Supply, Consumption, and Costs

In 2005, U.S. Garrison Kaiserslautern used 72,832 MWh of electricity at a cost of $4,177,588 and had a maximum demand of 14,382 KW. Also, 408,036 MBTU of district heat was used at a cost of $8,850,812 (Table 3).
Table 3. Energy supply, consumption, and costs, Garrison Kaiserslautern (2005).

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<td>Cost $</td>
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<td>5,549</td>
<td>18,933</td>
<td>12,276</td>
<td>337,660</td>
</tr>
<tr>
<td>Jun</td>
<td>5,608</td>
<td>19,134</td>
<td>13,185</td>
<td>340,076</td>
</tr>
<tr>
<td>Jul</td>
<td>5,553</td>
<td>18,947</td>
<td>12,523</td>
<td>343,873</td>
</tr>
<tr>
<td>Aug</td>
<td>5,688</td>
<td>19,407</td>
<td>12,327</td>
<td>344,759</td>
</tr>
<tr>
<td>Sep</td>
<td>5,707</td>
<td>19,472</td>
<td>12,280</td>
<td>365,244</td>
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<tr>
<td>Oct</td>
<td>5,868</td>
<td>20,022</td>
<td>12,853</td>
<td>295,429</td>
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<tr>
<td>Nov</td>
<td>6,166</td>
<td>21,038</td>
<td>13,624</td>
<td>312,208</td>
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<tr>
<td>Dec</td>
<td>6,590</td>
<td>22,485</td>
<td>12,876</td>
<td>344,733</td>
</tr>
<tr>
<td>Total</td>
<td>72,832</td>
<td>248,503</td>
<td></td>
<td>4,177,588</td>
</tr>
</tbody>
</table>

With the exception of heating oil, the costs were the same for the other installations. Pirmasens cost for heating oil was $50/MWHth.
4 Assessment Results

This Chapter includes the assessment results for which both cost and savings estimates were made. With the exception of lighting, the ECMs are organized first by the location (Kaiserslautern, Pirmasans, Ansbach area, Wiesbaden Schools), and then by system type as listed:

1. Building Envelope (BE)
2. Compressed Air (CA)
3. Central Energy Plant (CEP)
4. Electrical (EL)
5. HVAC (HV).

Appendix B to this report summarizes all ECMs.

4.1 Energy Costs Used To Determine Results

The energy costs used to determine results were:

- Heating: $65/MWh*
- Electricity: $80/MWh (Expected future costs)
- Fuel Oil: $51/MWh.

4.2 Kaiserslautern and Pirmasens Lighting (LI)

Table 4 lists the facilities with potential lighting ECMs.

<table>
<thead>
<tr>
<th>Facility</th>
<th>ECM</th>
<th>System Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>2233, 2281</td>
<td>Add daylight sensors to switch off lighting in work areas where daylight is available (skylights)</td>
<td>LI</td>
</tr>
<tr>
<td>2233, 2371, 2225, 4000</td>
<td>Switch off unnecessary lighting by adding occupancy sensors in areas where there is no activity</td>
<td>LI</td>
</tr>
<tr>
<td>2370, 2371, 2213, 4171</td>
<td>Change lamp type to more energy efficient</td>
<td>LI</td>
</tr>
<tr>
<td>4155 and others</td>
<td>Install energy efficient lighting in renovations</td>
<td>LI</td>
</tr>
<tr>
<td>all buildings</td>
<td>Install energy efficient LED exit-lights in renovations</td>
<td>LI</td>
</tr>
<tr>
<td>4171</td>
<td>Paint ceiling white to improve lighting conditions</td>
<td>LI</td>
</tr>
</tbody>
</table>

* $1.3 = 1 €.
4.2.1  LI #1: Install Energy Efficient LED Exit Lights All Buildings

4.2.1.1  Existing Conditions

Most buildings have ordinary fluorescent exit lights. The tube type is usually an 11W fluorescent tube. There are an estimated 250-300 exit lights in the buildings.

4.2.1.2  Solution

To improve energy efficiency of exit-lights, LED-lights should be used.

Instead of 11W a LED-light has a power input of 4W. The life time of LED-lights is much longer than that of fluorescent tubes.

4.2.1.3  Savings

Savings are calculated as:

\[
\text{Savings per fixture} = 24 \text{ hrs/day} \times 365 \text{ days/yr} \times 7\text{W} \times \frac{1\text{MW}}{1,000,000\text{W}} \times \frac{80}{\text{MWHe}} = 4.90 \text{ / yr (3.77 €/yr)}^*
\]

If all fixtures (estimated 270) are changed, the savings will be about $1325/yr.

4.2.1.4  Investment

An LED exit sign can cost between $30 and $250 in comparison to $20 and $100 for an incandescent and $125 and $200 for a fluorescent sign. Retrofit kits can be purchased to convert any exiting incandescent or fluorescent sign to an LED sign. The retrofit kit can cost $40, which includes all the necessary hardware for the conversion. Here a price difference of $40 (30 €)/fixture has been used.

4.2.1.5  Payback Calculation

The calculated payback will occur in:

\[
\text{Per fixture } \frac{40}{4.90} \text{ / yr} = 8.2 \text{ yrs}
\]

* $1.30 = 1 €.
The conclusion is that when the electrical system, lighting installation, or exit lighting in a building is renovated for technical reasons, more energy-efficient LED exit lighting fixtures should be installed.

4.2.2 LI #2: Install Occupancy Sensors To Turn Off Unnecessary Lighting—
All buildings: Restrooms, Lunchrooms, etc.

4.2.2.1 Existing Conditions

In most cases the lighting in restrooms, locker rooms, and lunch rooms is on all day. Building 2233 is a typical example.

4.2.2.2 Solution

Install occupancy sensors in restrooms, lunch rooms, etc to turn off the lighting when the rooms are unoccupied. In most cases, the occupancy time is only 2 to 3 hrs/day.

4.2.2.3 Savings

Assuming that the lighting can be switched off 70 percent of the time, the average lighting hours will be reduced from 10 hrs/day to 3 hrs/day.

The lighting capacity to be controlled by the occupancy sensor is typically 200W to 400W per room. Here it is assumed that there are 20 rooms where occupancy control could be added. The total lighting capacity in these is about 6 kW. Savings are calculated as:

\[
\text{Savings} = 7 \text{ hrs/day} \times 240 \text{ days/yr} \times 6 \text{ kW} \times \frac{1 \text{ kW}}{1000 \text{ kW}} \times \frac{80 \text{ / MWh}}{\text{$/MWh}} = 806 \text{ / yr (620 €/yr)}
\]

4.2.2.4 Investment

A rough cost estimate is $250 for the sensor and some wiring. In some cases (such as typical restrooms), the manual wall switch could be replaced by an occupancy sensing switch. Here a total cost of $5,000 (3,800 €) has been used to cover 20 rooms.

4.2.2.5 Payback Calculation

The calculated payback will occur in:

\[
\frac{5,000 \text{ / yr}}{806 \text{ / yr}} = 6.2 \text{ yrs}
\]
4.2.3  LI #3: Use Daylight Sensors To Turn Off Unnecessary Lighting  
Building 2233 Maintenance Area—2233 Main Hall

4.2.3.1  Existing Conditions

The main hall in Building 2233 has about 60 luminaires with 400W mercury vapor lamps. The total lighting capacity in the hall is about 26.4 kW including ballasts. There are windows and skylights to provide plenty of daylight. All lights were on even on a sunny day.

4.2.3.2  Solution

Add daylight sensor to switch off the lights when there is enough daylight.

When there is 7,500 to 10,000 lux outside, the lights (or part of the lights) can be switched off. The lux-level is 10,000 lux or more on sunny and partly cloudy days. Between February and October the outdoor lux level should be sufficient during the working hours to allow indoor lighting to be switched off.

4.2.3.3  Savings

Assuming that the lighting in the main hall can be switched off 60 percent of the time, the average lighting hours will be reduced from 10 hrs/day to 3 hrs/day. The lighting is needed more in winter time, during summer months the lights can be off all day. Savings are calculated as:

\[
\text{Savings} = 6 \text{ hrs/day} \times 240 \text{ days/yr} \times 26.4 \text{ kW} \times 1 \text{ MW/1000 kW} \times \$80 / \text{ MWh} = \$
\]

\[
3,041 / \text{ yr} \ (2,952 \ \text{€/yr})
\]

4.2.3.4  Investment

One daylight sensor can control lighting in several rooms connected to the lighting power distribution. Connecting the sensor to the lighting power distribution may require some changes in the distribution boards, it is possible to control lights in zones or even by contactor. A rough cost estimate is $1,200 for the sensor and some wiring, not including major changes in distribution boards. Here a total cost of $2,500 (1900 €) has been used to cover changes in two lighting areas.

If the electrical installation in Building 2233 is renovated, daylight control should be included.
4.2.3.5 Payback Calculation

The calculated payback will occur in:

\[ \frac{2,500}{3,041} \text{ yr} = 0.8 \text{ yrs} \]

4.2.4 LI #4: Use Daylight Sensors To Turn Off Unnecessary Lighting,
Building 2233—Engine Repair and Other Areas on the North side

This was separated from the main hall lighting because here the task lighting will remain on whereas in the main hall all lighting switches off by daylight sensor.

4.2.4.1 Existing Conditions

The engine repair workshop area has a very high fluorescent task lighting capacity at about 2m height above the work areas. In addition to this there is general lighting in the hall with a mercury vapor lamp capacity of about 8 kW (20 fixtures). There are other areas on the North side of the building where the lighting installation is similar. The total amount of 400W mercury vapor lamps is about 50 (22 kW including ballast). There are windows on the North side of the building to provide some daylight. All lights were on even on a sunny day.

4.2.4.2 Solution

Add daylight sensor to switch off the mercury vapor lamps when there is enough daylight. The task lights are on during working hours.

When the mercury vapor lamps are switched off by the daylight sensor they require a time to cool before they can be switched on again. This is not an issue in the engine repair because there is enough task lighting on all the time.

4.2.4.3 Savings

Assuming that the mercury vapor lighting can be switched off 70 percent of the time, the average lighting hours will be reduced from 10 hrs/day to 3 hrs/day. The lighting is needed more in winter time, during summer months the lights will be off all day. Savings are calculated as:
Savings = 7 hrs/day x 240 days/yr x 22 kW x 1MW/1000kW x $80 / MWh =
$2,957 / yr (2,275 €/yr)

4.2.4.4  Investment

A rough cost estimate is $1,200 for the sensor and some wiring, not including major changes in distribution boards. Here a total cost of $2,500 (1,900 €) has been used to cover changes in two lighting areas.

If the electrical installation in Building 2233 is renovated, daylight control should be included.

4.2.4.5  Payback Calculation

The calculated payback will occur in:

$2,500 / $2,957 / yr = 0.9 yrs

4.2.5  LI #5: Install Daylight Sensors To Switch Off Unnecessary Lighting During Daylight Hours—Building 2281 Warehouse SAK

4.2.5.1  Existing Conditions

The building consists of three parts, the one at the West end has stacking shelves placed building lengthwise (E-W-direction) with seven aisles. The sections in the middle and east end have stack shelves placed crosswise with one main aisle in the middle of the building. There are luminaires between the shelves in all aisles. The luminaires have fluorescent 58W tubes. The total lighting capacity (including ballasts) is about 17.5 kW at the West end and 7.3 kW in the middle and east end. There are windows on the South side of the building and skylights to provide plenty of daylight. All lights were on even on a sunny day (for example, see Figure 2).

4.2.5.2  Solution

Add daylight sensor to switch off the fluorescent lighting between the shelves when there is enough daylight. The lights on the main aisle and the emergency lights should be on all the time for safety reasons. Some task lighting should remain on in the work area by the main door.
4.2.5.3 Savings

Assuming that the lighting can be switched off 70 percent of the time, the average lighting hours will be reduced from 10 hrs/day to 3 hrs/day. The lighting is needed more in winter time, during summer months the lights can be off all day. The lighting capacity to be controlled by the daylight sensor is about 18 kW. Savings are calculated as:

\[
\text{Savings} = 7 \text{ hrs/day} \times 240 \text{ days/yr} \times 18 \text{ kW} \times 1 \text{MW/1000kW} \times $80 / \text{MWh} = $2,419 / \text{yr} (1,861 \text{ €/yr})
\]

4.2.5.4 Investment

A rough cost estimate is $1,200 for the sensor and some wiring, not including major changes in distribution boards. Here a total cost of $2,500 (1,900 €) has been used to cover changes in the two lighting areas.

4.2.5.5 Payback Calculation

The calculated payback will occur in:

\[
$2,500 / $2,419 / \text{yr} = 0.9 \text{ yrs}
\]
4.2.6 LI #6: Install Daylight Sensors To Switch Off Unnecessary Lighting During Daylight Hours, Building 4000 Maintenance—Maintenance Area and Body Shop

4.2.6.1 Existing Conditions

The main maintenance hall in the middle of the building and the body shop on the east side of the building have large skylights facing North. The lighting installation consists of ceiling lights and some task lighting along the walls and in the vehicles under repair. The lighting in the main hall consists of four rows of luminaires with 400W mercury vapor lamps. The lights can be controlled in groups of four.

The total number of fixtures in the main hall is 48, having a total lighting capacity of 21.1 kW (including ballasts). During the site visit about 50 percent of the lights in the main hall were on.

The Body Shop has 28 fixtures with a total lighting capacity of 12.3 kW (including ballasts). During the site visit all the lights in the area hall were on.

4.2.6.2 Solution

Add daylight sensor to switch off the ceiling lighting when there is enough daylight (more than 7,500 or 10,000 lux). The task lighting should remain on in the work area.

A mercury vapor lamp takes some time to cool before it can be switched on again after switch-off. Rapid changes in daylight level are not very common.

4.2.6.3 Savings

Assuming that the lighting is partly switched off manually during the summer months, the saving is based on an assumption that the daylight control will switch the lights off 40 percent of the time, leading to an average saving of about 4 hrs/day. The lighting is needed more in winter time, during summer months the lights can be off all day. The lighting capacity to be controlled by the daylight sensor is about 33 kW. Savings are calculated as:
Savings = 4 hrs/day x 240 days/yr x 33 kW x 1MW/1000kW = 31.68 MWh/yr
Savings = 31.68 MWh/yr x $80 / MWh = $2,534 / yr (1,949 €/yr)

4.2.6.4 Investment

A rough cost estimate is $1,200 for the daylight sensor and some wiring, not including major changes in distribution boards. Here a total cost of $2,500 (1,900 €) has been used to cover changes in the two lighting areas.

4.2.6.5 Payback Calculation

The calculated payback will occur in:

$2,500 / $2,534 / yr = 1.0 yrs

4.2.7 LI #7: Install Daylight Sensors To Switch Off Unnecessary Lighting During Daylight Hours, Building 4000 Maintenance—Apprentice Workshop

4.2.7.1 Existing Conditions

The Apprentice workshop on the lower level of the building is situated on the North-West corner and has large windows to both directions. The lighting in the room consists of 42 fixtures with two 36W fluorescent tubes in each, having a total lighting capacity of 4.1 kW (including ballasts). During the site visit on a bright day all the lights were on.

4.2.7.2 Solution

Add daylight sensor to switch off 3/4 of the lighting when there is enough daylight. The 1/4 lighting should give enough task lighting in all conditions.

4.2.7.3 Savings

Assuming that the lighting can be switched off 70 percent of the time, the average lighting hours will be reduced from 10 hrs/day to 3 hrs/day. The lighting is needed more in winter time, during summer months the lights can be off all day. The lighting capacity to be controlled by the daylight sensor is about 3.1 kW. Savings are calculated as:

Savings = 7 hrs/day x 240 days/yr x 3.1 kW x 1MW/1000kW = 5.21 MWh/yr
Savings = 5.21 MWh/yr x $80 / MWh = $417 / yr (321 €/yr)
4.2.7.4 Investment

A rough cost estimate is $1,200 for the daylight sensor and some wiring, not including major changes in distribution boards. The 1/4 lighting should be separated from the 3/4 of daylight-controlled lighting. A total cost of $1,800 (1,400 €) has been assumed to cover changes in zoning.

4.2.7.5 Payback Calculation

The calculated payback will occur in:

\[
\frac{1,800}{417/\text{yr}} = 4.3 \text{ yrs}
\]

The total savings and investments for lighting ECMs in Building 4000 (LI #6 + LI#7) are:

- Savings = 31.68 MWh/yr + 5.21 MWh/yr = 36.89 MWh/yr
- Savings = 36.89 MWh/yr x $80 / MWh = $2951/yr
- Total Investment = $2,500 + 1,800 = $4,300

4.2.8 LI #8: Install Occupancy Sensors To Turn Off Unnecessary Lighting—Building 2371 Shipping and Receiving

4.2.8.1 Existing Conditions

The building is in operation 24 hrs a day. In the night shift there are usually three people, working at one end of the building. Lights are on all the time in this part and also in the separate storage room in the middle. The storage room has fluorescent lighting, the main part of the building having fixtures with mercury vapor or high pressure sodium lamps.

4.2.8.2 Solution

Install occupancy sensors in the storage room in the middle of the building. The occupancy time is only 2 to 3 hrs/day. Some security lighting should be on all the time.

4.2.8.3 Savings

Assuming that the lighting can be switched off 70 percent of the time, the average lighting hours will be reduced from 10 hrs/day to 3 hrs/day.
The lighting capacity to be controlled by the occupancy sensor is about 3.5 kW (including ballasts), assuming that out of the total amount of 28 luminaires four luminaires with 2x58W remain on all the time. Savings are calculated as:

\[
\text{Savings} = 7 \text{ hrs/day} \times 240 \text{ days/yr} \times 3.5 \text{ kW} \times \frac{1 \text{ MW}}{1000 \text{ kW}} = 5.88 \text{ MWh}
\]

\[
\text{Savings} = 5.88 \text{ MWh} \times \frac{80}{\text{MWh}} = \frac{470}{\text{yr}} (362 \text{€/yr})
\]

4.2.8.4  Investment

A rough cost estimate is $250 for the sensor and some wiring. Here a total cost of $500 (385 €) has been assumed to cover changes in wiring to separate the security lights from the occupancy controlled luminaires.

\[
\frac{$500}{$470/\text{yr}} = 1.1 \text{ yrs}
\]

4.2.9  LI #9: Install Occupancy Sensors To Turn Off Unnecessary Lighting—Building 2370 Security warehouse

4.2.9.1  Existing Conditions

The high security section (West end) of building is in operation about 10 hrs a day, but the lighting is on 24 hrs/day for security reasons. The area is fenced inside the KAD area. The lighting consists of 42 lighting fixtures with 400W mercury vapor or 250W high pressure sodium lamps (about 50/50 percent).

4.2.9.2  Solution

Install movement detector sensors at the fence and at the door to switch on all lights in the warehouse in unoccupied hours. Some security lighting should be on all the time.

If there is a recording surveillance camera in the warehouse, the camera may be connected to a movement detector and record only when there is movement (and lights are on). New camera types do not need light to function and record.

4.2.9.3  Savings

Assuming that the lighting can be switched off from 1606 on weekdays and 24 hrs during weekends reduces the weekly lighting time by 118 hrs/week.
The lighting capacity to be controlled by the occupancy sensor is about 13.8 kW (including ballasts). Savings are calculated as:

\[
\text{Savings} = 118 \text{ hrs/week} \times 52 \text{ weeks/yr} \times 13.8 \text{ kW} \times 1 \text{MW}/1000\text{kW} = 84.7 \text{ MWh}
\]

\[
\text{Savings} = 84.7 \text{ MWh} \times 80 \text{ / MWh} = 6,774 \text{ / yr (5,211 €/yr)}
\]

4.2.9.4  Investment

A rough cost estimate is $250 for the sensor and some wiring. Here a total cost of $2,500 (1,900 €) has been assumed to cover five IR-sensors, wiring and some security lighting.

4.2.9.5  Payback Calculation

The calculated payback will occur in:

\[
\frac{2,500}{6,774} \text{ / yr} = 0.4 \text{ yrs}
\]

4.2.10 LI #10: Install Occupancy Sensors To Turn off Unnecessary Lighting—Building 2225 Paint Booth

4.2.10.1  Existing Conditions

There is a paint booth in KAD Building 2225 that has a high lighting level. The lights are on even if there is nobody working in the paint booth. The typical lighting capacity per booth is 2.5 kW.

4.2.10.2  Solution

Install occupancy sensors in the paint booths to switch off most lights when there is no activity. Two-thirds of the lights could be switched off during the drying process when there is nobody in the booth. One third should remain on during working hours for safety reasons.

4.2.10.3  Savings

Assuming that two-thirds of the lighting can be switched off 70 percent of the time, the full lights on lighting hours will be reduced from 10 hrs/day to 3 hrs/day. The lighting capacity to be controlled by the occupancy sensor is 1.8 to 3.6 kW. Here it is assumed that the lighting capacity is 2.5 kW/booth. Savings are calculated as:
Savings per booth = 7 hrs/day x 240 days/yr x 2.5 kW x 1MW/1000kW x $80 / MWh = $336 / yr (258 €/yr)

4.2.10.4 Investment

A rough cost estimate is $250 for the sensor and some wiring. Here a total cost of $400 (300 €) has been used to cover the three paint booths.

4.2.10.5 Payback Calculation

The calculated payback will occur in:

\[
\frac{400}{336} \text{ yr} = 1.2 \text{ yrs}
\]

4.2.11 LI #11: Install Occupancy Sensors To Turn Off Unnecessary Lighting—Building 4000 Paint Booths

4.2.11.1 Existing Conditions

There are two paint booths in Pirmasens Building 4000 that have a high lighting level. The lights are on even if there is nobody working in the paint booth. The typical lighting capacity per booth is 2.8 kW to 5.5 kW.

4.2.11.2 Solution

Install occupancy sensors in the paint booths to switch off most lights when there is no activity. Two-thirds of the lights could be switched off during the drying process when there is nobody in the booth. One third should remain on during working hours for safety reasons.

4.2.11.3 Savings

Assuming that two-thirds of the lighting can be switched off 70 percent of the time, the full lights on lighting hours will be reduced from 10 hrs/day to 3 hrs/day. The lighting capacity to be controlled by the occupancy sensor is in the different booths 1.8 to 3.6 kW. Here it is assumed that the lighting capacity is 2.5 kW/booth. Savings are calculated as:

\[
\text{Savings per booth} = 7 \text{ hrs/day} \times 240 \text{ days/yr} \times 2.5 \text{ kW} \times 1 \text{MW}/1000\text{kW} \times 80 \text{ / MWh} = 672 \text{ / yr} (517 \text{ €/yr})
\]
4.2.11.4 **Investment**

A rough cost estimate is $250 for the sensor and some wiring. Here a total cost of $800 (600 €) has been used to cover the two paint booths.

4.2.11.5 **Payback Calculation**

The calculated payback will occur in:

\[
\frac{800}{672/yr} = 1.2 \text{ yrs}
\]

4.2.12 **LI #12: Turn Off Halogen Lights When Stacker Is Not in Use—Building 2281 Stacker lights**

4.2.12.1 **Existing Conditions**

In the middle and east end part of the building there is a stack lift for each aisle on both sides of the main aisle. Each stack lift has two halogen lights of about 150W. At the time of the visit three stack lifts had their halogen lights on although the stackers were not being used.

4.2.12.2 **Solution**

Repair the light controls on the stack lifts to avoid unnecessary lighting. The lights should be checked regularly to detect malfunctions.

4.2.12.3 **Savings**

Assuming that two stackers have the lights on all the time, the unnecessary lighting capacity is about 600W. The stack lift lights are on only when the lift is being used. The operation time per stacker is assumed to be about 10 minutes/day. Savings are calculated as:

\[
\text{Savings} = 23.8 \text{ hrs/day} \times 365 \text{ days/yr} \times 600W \times 1\text{MWh/1,000,000W} = 5.212 \text{ MWh/yr}
\]

\[
\text{Savings} = 5.212 \text{ MWh/yr} \times $80 / \text{MWh} = $417/ \text{yr} (318 \text{ €/yr})
\]

4.2.12.4 **Investment**

A rough cost estimate is $100 for the stack lift light contactor replacement per stacker. The cost should be included in the regular maintenance of the equipment. Here a total cost of $200 (150 €) has been assumed.
4.2.12.5 Payback Calculation

The calculated payback will occur in:

\[
\frac{200}{414} \text{ / yr} = 0.5 \text{ yrs}
\]

4.2.13 LI #13: Replace Lamp with More Efficient Type—Building 2371

4.2.13.1 Existing Conditions

In the warehouses, there are several different types of lighting fixtures with 400W mercury vapor lamps and 250W high pressure sodium lamps. Building 2371 has 200 lighting fixtures with about 40 percent mercury vapor lamps and 60 percent high pressure sodium lamps. Mercury vapor lamps have a lighting capacity of 35.2 kW (including ballasts).

4.2.13.2 Solution

Change mercury vapor lamps into high pressure sodium lamps.

Generally it is possible to replace 400W mercury vapor lamps by 250W high pressure sodium lamps without changes in the fixture, but if the fixture is old, the ballast may not be suitable for lamp type change. The high pressure sodium lamp produces more light with less power input—however, the color of the light from hp sodium lamps is different.

When the lamps are changed, the luminaires should be cleaned to improve reflecting capacity.

4.2.13.3 Savings

The lighting is usually on about 10 hrs on workdays. The savings have been calculated using 10 hrs/day. The lighting capacity will be reduced from 32 kW to 20 kW. Savings are calculated as:

\[
\text{Savings} = 10 \text{ hrs/day} \times 240 \text{ days/yr} \times 13.6 \text{ kW} = 32,640 \text{ KWh}
\]

\[
\text{Savings} = 32,640 \text{ kWh} \times \frac{1 \text{ MW}}{1000 \text{ kWh}} \times \frac{80}{\text{ MWh}} = \$2,611 / \text{ yr} (2,008 \text{ €/yr})
\]

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.
4.2.13.4 Investment

Good quality high pressure sodium lamps are slightly more expensive than mercury vapor lamps, but the difference is very small (about $5 to $10/lamp). The number of lamps to be changed is about 80. This leads to a difference of $800 (615 €) in lamp change costs. The estimated lamp life-time is 10,000 – 15,000 hrs, so the lamps are changed every 4 to 5 yrs.

4.2.13.5 Payback Calculation

The calculated payback will occur in:

\[ \frac{800}{2,611/\text{yr}} = 0.3 \text{ yrs} \]

4.2.14 LI #14: Replace Lamp with More Efficient Type—Building 2370

4.2.14.1 Existing Conditions

In the warehouses there are several different types of lighting fixtures with 400W mercury vapor lamps and 250W high pressure sodium lamps. Building 2370 high security section has 42 lighting fixtures with about 50 percent mercury vapor lamps and 50 percent high pressure sodium lamps. Mercury vapor lamps have a lighting capacity of 9.2 kW (including ballasts).

4.2.14.2 Solution

Change mercury vapor lamps into high pressure sodium lamps.

Generally it is possible to replace 400W mercury vapor lamps by 250W high pressure sodium lamps without changes in the fixture, but if the fixture is old, the ballast may not be suitable for lamp type change. The high pressure sodium lamp produces more light with less power input, however the color of the light from hp sodium lamps is different.

When the lamps are changed, the luminaires should be cleaned to improve reflecting capacity.

4.2.14.3 Savings

The lighting is usually on about 10 hrs on workdays. In the 2370 security warehouse the lights are on all the time. The savings have been calculated
using 10 hrs/day. The lighting capacity in this building will be reduced from 8.4 kW to 5.3 kW. Savings are calculated as:

\[
\text{Savings} = 10 \text{ hrs/day} \times 240 \text{ days/yr} \times 3.57 \text{ kW} = 8,658 \text{ KWh}
\]

\[
\text{Savings} = 8,658 \text{ KWh} \times 1 \text{ MWh/1000kWh} \times \$80 / \text{ MWh} = \$685 / \text{ yr} (527 \text{ €/yr})
\]

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.2.14.4 Investment

Good quality high pressure sodium lamps are slightly more expensive than mercury vapor lamps, but the difference is very small (about $5 to $10/lamp). The number of lamps to be changed is about 21. This leads to a difference of $210 (160 €) in lamp change costs. The estimated lamp lifetime is 10,000 – 15,000 hrs, so the lamps are changed every 4 to 5 yrs.

4.2.14.5 Payback Calculation

The calculated payback will occur in:

\[
\frac{\$210}{\$685 / \text{ yr}} = 0.3 \text{ yrs}
\]

4.2.15 LI #15: Replace Lamp with More Efficient Type—Building 2213

4.2.15.1 Existing Conditions

In the warehouses there are several different types of lighting fixtures with 400W mercury vapor lamps and 250W high pressure sodium lamps. Building 2213 has 20 lighting fixtures with mercury vapor lamps having a lighting capacity of 8.8 kW (including ballasts).

4.2.15.2 Solution

Change mercury vapor lamps into high pressure sodium lamps.

Generally it is possible to replace 400W mercury vapor lamps by 250W high pressure sodium lamps without changes in the fixture, but if the fixture is old, the ballast may not be suitable for lamp type change. The high pressure sodium lamp produces more light with less power input—however, the color of the light from hp sodium lamps is different.
When the lamps are changed, the luminaires should be cleaned to improve reflecting capacity.

4.2.15.3 Savings

The lighting is usually on about 10 hrs on workdays. The lighting capacity in this building will be reduced from 8 kW to 5 kW. Savings are calculated as:

$$\text{Savings} = 10 \text{ hrs/day} \times 240 \text{ days/yr} \times 3.4 \text{ kW} = 8,160 \text{kWh}$$
$$\text{Savings} = 8,160 \text{kWh} \times 1\text{MW}/1000\text{kW} \times $80 / \text{MWh} = $653 / \text{yr} (502 \text{ €/yr})$$

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.2.15.4 Investment

Good quality high pressure sodium lamps are slightly more expensive than mercury vapor lamps, but the difference is very small (about $5 to $10/lamp). The number of lamps to be changed is about 20. This leads to a difference of $200 (150 €) in lamp change costs. The estimated lamp life-time is 10,000 to 15,000 hrs, so the lamps are changed every 4 to 5 yrs.

4.2.15.5 Payback Calculation

The calculated payback will occur in:

$$\frac{$200}{$653 / \text{yr}} = 0.3 \text{ yrs}$$

4.2.16 LI #16: Replace Lamp With More Efficient Type—Building 4171

4.2.16.1 Existing Conditions

In the warehouses there are several different types of lighting fixtures with 400W mercury vapor lamps and 250W high pressure sodium lamps. Building 4171 building part C has 42 mercury vapor lamps with a total lighting capacity of 18.4 kW (including ballasts).

4.2.16.2 Solution

Change mercury vapor lamps into high pressure sodium lamps.
Generally it is possible to replace 400W mercury vapor lamps by 250W high pressure sodium lamps without changes in the fixture, but if the fixture is old, the ballast may not be suitable for lamp type change. The high pressure sodium lamp produces more light with less power input—however, the color of the light from hp sodium lamps is different.

When the lamps are changed, the luminaires should be cleaned to improve reflecting capacity.

4.2.16.3  Savings

The lighting is usually on about 10 hrs on workdays. The lighting capacity in this building will be reduced from 16.8 kW to 10.5 kW. Savings are calculated as:

\[
\text{Savings} = 10 \text{ hrs/day} \times 240 \text{ days/yr} \times 7.14 \text{ kW} = 17,136 \text{kWh/yr}
\]

\[
\text{Savings} = 17,136 \text{kWh/yr} \times \frac{1 \text{MW}}{1000 \text{kW}} \times \frac{80 \text{$/MWh}}{1 \text{MWh}} = 1371 \text$/yr (1055 €/yr)
\]

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.2.16.4  Investment

Good quality high pressure sodium lamps are slightly more expensive than mercury vapor lamps, but the difference is very small (about $5 to $10/lamp). The number of lamps to be changed is about 42. This leads to a difference of $420 (320 €) in lamp change costs. The estimated lamp lifetime is 10,000 – 15,000 hrs, so the lamps are changed every 4 to 5 yrs.

Payback: $420/$653/yr = 0.3 yrs

4.2.17  LI #17: Replace Lamp With More Efficient Type—Building 4171

Warehouse: Fluorescent Lights

4.2.17.1  Existing Conditions

In 4171 the warehouse sections A and B have fluorescent lighting. The lighting fixtures are possibly from the 1970s or 1980s and have a white reflectors and 65W fluorescent tubes. Total number of fixtures (and tubes) is about 580.
4.2.17.2 Solution

Change old thicker fluorescent tube (65W) into more energy efficient tube type (58W).

Usually it is possible to replace the tube type without changes in the luminaire, but if the fixture is old, the ballast may not be suitable for lamp type change. This should be checked before changing the tube type.

When the fluorescent tubes are changed, the luminaires should be cleaned to improve their reflecting capacity. Changing white reflectors to brighter ones is not recommended, the expected remaining life-time of the existing luminaires is 10 to 15 yrs.

4.2.17.3 Savings

The lighting capacity per tube is reduced by 7W and in all fixtures 4.1 kW. The lighting is usually on about 10 hrs on workdays. Savings are calculated as:

\[
\text{Savings} = 10 \text{ hrs/day} \times 240 \text{ days/yr} \times 4.1 \text{ kW} = 9,840 \text{ kWh/yr}
\]
\[
\text{Savings} = 10 \text{ hrs/day} \times 240 \text{ days/yr} \times 4.1 \text{ kW} \times 1\text{MWh}/1000\text{kWh} \times $80 / \text{MWh} = $787 / \text{yr} (600 \text{ €/yr})
\]

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.2.17.4 Investment

There is no difference in tube price for the 65W and 58W tubes. All tubes should be replaced at the same time to minimize change work costs.

4.2.17.5 Payback Calculation

There will be zero payback time; tubes need to be changed anyway after about 10,000 hrs of use (approximately every 4 yrs).
4.2.18 LI #18: Install Energy Efficient Lighting in Renovations—Building 4155 (Under Renovation) and Other Buildings

4.2.18.1 Existing Conditions

In 4155 new lighting fixtures with ordinary 36W fluorescent tubes were being installed in the rooms under renovation. It is estimated that there will be 200 fixtures.

4.2.18.2 Solution

To improve energy efficiency of old fluorescent lighting fixtures, it is not possible to change into the new more efficient and low power input tube type to T5, but new fixtures are needed. By renovating the fixtures less fixtures are needed for the same amount of light. The power input of a single tube 58W fixture will go from 73W (including ballast) down to about 55W if a T5 fixture is installed.

4.2.18.3 Savings

Savings are calculated as:

\[
\text{Savings} = 200 \text{ fixtures} \times 10 \text{ hrs/day} \times 240 \text{ days/yr} \times 18W = 8,640 \text{ KWh/yr}
\]

\[
\text{Savings} = 8,640 \text{ kWh/yr} \times 1\text{MWh/1,000,000W} \times \$80 / \text{MWh} = \$691 / \text{yr} (532 \text{ €/yr})
\]

4.2.18.4 Investment

The new T5 fixture costs about $180 and an ordinary single-tube 58W fixture costs (depending on manufacturer and luminaire type) $130 to $180. The price difference is assumed to be $5 (3.84 €) or $1000 (769 €) for 200 fixtures.

4.2.18.5 Payback Calculation

The calculated payback will occur in:

\[
\text{Per fixture } \frac{1,000}{691} / \text{yr} = 1.4 \text{ yrs}
\]

The conclusion is that when the electrical system or lighting installation in a building is renovated for technical reasons and new fixtures are installed, more energy efficient T5 fixtures should be installed instead of the ordinary type.
According to a fluorescent tube manufacturer’s tests the expected life-time of T5 lamps is about 20,000 hrs whereas for an ordinary 36W or 58W tube the efficient life-time is only 4,000 hrs, after this the amount of light from the tube will begin to decrease.

**4.2.19 LI #19: Paint Ceiling White To Improve Lighting Level—Building 4171 Outbound Storage**

4.2.19.1 Existing Conditions

In 4171 the building section C has a dark interior ceiling covered with mineral wool insulation elements. This leads in decreased lighting level.

4.2.19.2 Solution

Paint the ceiling white with paint suitable for mineral wool surfaces. Also a white surface material is possible—this would keep fibers from the mineral wool from being carried into the indoor air by air movement.

4.2.19.3 Savings

No saving can be indicated; the lights in the warehouse are on all day. The lighting level would be improved. This has an effect on worker safety and indoor environment. The following sections include calculated savings.

4.2.19.4 Investment

In the Fort Stewart, GA energy audit report* the cost of painting was estimated as $2.40/sq ft. The area of Section C is roughly 40,000 sq ft. The cost of painting the ceiling is about $96,000 (73,800 €).

4.2.19.5 Payback Calculation

The calculated payback is unknown.

**4.2.20 ECM Summary**

Table 5 lists the ECM summary for Kaiserslautern and Pirmasens lighting (LI).

---

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings MWh/yr</th>
<th>$K/yr</th>
<th>Thermal Savings MWh/yr</th>
<th>$K/yr</th>
<th>Additional Savings $K/yr</th>
<th>Total Savings $K/yr</th>
<th>Investment $K</th>
<th>Simple Payback yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>LI1</td>
<td>Install Energy Efficient LED Exit Lights - Kaiserslautern and Pirmasens</td>
<td>16</td>
<td>1.3</td>
<td>1.3</td>
<td></td>
<td>10.8</td>
<td>8.2</td>
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<tr>
<td>LI2</td>
<td>Install Occupancy Sensors to Turn off Unnecessary Lighting, All buildings: Restrooms, lunchrooms, etc – Kaiserslautern and Pirmasens</td>
<td>10</td>
<td>0.8</td>
<td>0.8</td>
<td></td>
<td>5.0</td>
<td>6.2</td>
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<tr>
<td>LI3</td>
<td>Use Daylight Sensors to Turn off Unnecessary Lighting, Building 2233 Maintenance Area</td>
<td>37</td>
<td>3.0</td>
<td>3.0</td>
<td></td>
<td>2.5</td>
<td>0.8</td>
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<td>LI4</td>
<td>Use Daylight Sensors to Turn off Unnecessary Lighting, Building 2233 - Engine repair and other areas on the North side</td>
<td>40</td>
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<td>LI5</td>
<td>Install day light sensors to switch off unnecessary lighting during daylight hours, Building 2281 Warehouse SAM</td>
<td>30</td>
<td>2.4</td>
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<td></td>
<td>2.5</td>
<td>1.0</td>
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<td></td>
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<tr>
<td>LI6</td>
<td>Install day light sensors to switch off unnecessary lighting during daylight hours, Building 4000 Maintenance Area and Bodyshop</td>
<td>37</td>
<td>3.0</td>
<td>3.0</td>
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<td>2.95</td>
<td>4.3</td>
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<td>LI7</td>
<td>Install day light sensors to switch off unnecessary lighting during daylight hours, Building 4000 Maintenance-Apprentice Workshop</td>
<td>5.21</td>
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<tr>
<td>LI8</td>
<td>Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 2371 Shipping and receiving</td>
<td>6</td>
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<td>1.1</td>
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<td>LI9</td>
<td>Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 2370 Security warehouse</td>
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<td>0.4</td>
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<td>LI10</td>
<td>Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 2225 Paint booth</td>
<td>4.2</td>
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<td>0.4</td>
<td>1.2</td>
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<td></td>
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<tr>
<td>LI11</td>
<td>Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 4000 Paint booths</td>
<td>8.4</td>
<td>0.7</td>
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<td>LI12</td>
<td>Turn off Halogen Lights When Stacker is not in Use, Building 2281 Stacker lights</td>
<td>5.2</td>
<td>0.4</td>
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<td>0.2</td>
<td>0.5</td>
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</tr>
<tr>
<td>LI13</td>
<td>Replace Mercury Vapor Lamp with More Efficient Type, Building 2371</td>
<td>33</td>
<td>2.6</td>
<td>2.6</td>
<td></td>
<td>0.8</td>
<td>0.3</td>
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<tr>
<td>LI14</td>
<td>Replace Mercury Vapor Lamp with More Efficient Type, Building 2370</td>
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<td>0.7</td>
<td>0.7</td>
<td></td>
<td>0.2</td>
<td>0.3</td>
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<tr>
<td>LI15</td>
<td>Replace Mercury Vapor Lamp with More Efficient Type, Building 2213</td>
<td>8</td>
<td>0.7</td>
<td>0.7</td>
<td></td>
<td>0.2</td>
<td>0.3</td>
<td></td>
<td></td>
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<tr>
<td>LI16</td>
<td>Replace Mercury Vapor Lamp with More Efficient Type, Building 4171</td>
<td>17</td>
<td>1.4</td>
<td>1.4</td>
<td></td>
<td>0.4</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LI17</td>
<td>Replace Fluorescent Lamp with More Efficient Type, Building 4171 Warehouse: fluorescent lights</td>
<td>10</td>
<td>0.8</td>
<td>0.8</td>
<td></td>
<td>0.4</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LI18</td>
<td>Install Energy Efficient Lighting in Renovations, Building 4155 (under renovation) and other buildings</td>
<td>8.6</td>
<td>0.725</td>
<td>0.725</td>
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<td>1.025</td>
<td>1.40</td>
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<tr>
<td>LI20</td>
<td>Improve Lighting Efficiency In Hangers (No Economic Analysis)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Total</td>
<td>Kaiserslautern and Pirmasens Lighting ECMs</td>
<td>367</td>
<td>29.52</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>29.5</td>
<td>36.8</td>
<td>1.2</td>
</tr>
</tbody>
</table>
4.3 Kaiserslautern Building Envelope (BE)

4.3.1 BE #1: Use Transparent Plastic Panels Behind Glass Sash—Building 2233

4.3.1.1 Existing Conditions

Building 2233 is a large tall building used to repair all sizes of Army vehicles (Figure 3). The building is over 50 yrs old, but in good condition. The building has a very high percentage of single pane glass in the outer walls and roof. Above a height of approximately 4m the walls are mostly glass. There are also large skylights in the roof area allowing sunlight to enter the building. This provides a lot of natural light for the building occupants and general building lighting is not needed on bright days. The glass area in the roof is approximately 44,000 sq ft in area and the window area in the walls is estimated to be 26,000 sq ft.

![Figure 3. Kaiserslautern Building 2233.](image)

The single pane glass creates thermal problems inside the building. First it has a poor insulating value and much building heat is loss to the outside in the winter. Second, the operable sections of the glass areas are hard to close. These openings are needed in the summer to help vent off the warm air that collects in the upper region of the building. If the windows do not close well, the resulting openings increase the amount of infiltration that enters the building in the winter making it more difficult to heat the building. Third the sunshine can enter the building causing an increased cool-
ing load in the summer. Since there is no way to lower the summertime building temperature other than opening doors to allowing outside air to flow through the building the space temperatures become so warm that an additional 15-minute break is provided to the workers in the morning and afternoon on hot days.

4.3.1.2  Solution

Install transparent plastic panels behind the existing glass windows. Place the new panels as close to the glass windows as possible to provide a dead air space. The windows need to be inspected before the plastic panels are installed. Replace all broken windows and seal all openings and cracks between the windows, frames, and building structure. Remove operable hardware that allows the windows to open so that it will not interfere with the panel installation. Frame around locations where stacks penetrate the window area and where exhaust fans are planned to be placed.

The new plastic panels will allow most of the natural light to enter the building. The panels will provide a resistance to heat transfer due to layers of isolated air spaces in the panels. The proposed panel has three such layers providing an insulation value of approximately 0.5 Btu/sq ft/°F. It is planned to place these panels immediately under the existing windows leaving an air space as narrow as possible for an insulation value of approximately 0.35 Btu/sq ft/°F for the panel/window combination.

4.3.1.3  Savings

The placement of the transparent panels behind the existing windows will reduce the heat loss through the windows by 70 percent. Savings are calculated as:

\[
Q = (1.17 - 0.35) \text{ Btu/sq ft/°F} \times 70,154 \text{ sq ft} \times (64.4 - 39) \text{ °F} \times 6000 \text{ hrs/yr} / 3413000 \text{ Btu/MWH} = 2569 \text{ MWH/yr}
\]

The total energy cost savings is therefore $167,000 or 128,000 €/yr:

Cost Savings = (2,569) MWHth X $65/MWh = $167,000/yr

4.3.1.4  Investment

The estimated cost to prepare the underside of the windows and install the new transparent panels is $15/sq ft or $1,052,000 (809,000 €).
4.3.1.5 Payback Calculation

The resulting payback period for the window enhancement is 6.3 yrs.

4.3.2 BE #2: Reduce Solar Heat Load by Use of Conventional or Spectrally Selective Solar Film, Building 2233

4.3.2.1 Existing Conditions

For existing conditions in Building 2233, see BE #1.

4.3.2.2 Solution

Install solar film on the inside of the existing glass windows. The windows need to be inspected before the solar film is installed to ensure there are no cracked panes, loose glazing, spaces between the frames and the building, operable windows that do not close, etc. All openings between the window frames and building structure must be properly sealed and other repairs must be made as required. Openings where stacks penetrate the windows for exhaust fans must be properly framed to eliminate infiltration of outside air, and contribute to the “stack effect” of exfiltration in the winter.

There are two different types of window film, conventional and “spectrally-selective.” Conventional dark and reflective applied window films successfully block a significant amount of solar heat, thereby reducing the cooling problem in the interior space. However, these same films reduce a significant amount of visible light through the glass. The result, on many days of reduced sunlight, is that increased illumination is required, thus increasing both the heat in the space and the energy required to maintain the proper light levels.

The term “spectrally selective” refers to the ability of the film to select or “let in” desirable daylight, while blocking out undesirable heat. Most dark and reflective films transmit less than 35 percent of visible light and correspondingly appear unclear. True spectrally selective film blocks minimally less heat than the darkest conventional films (2 to 10 percent depending on the manufacturer), while typically transmitting 70 percent of the visible light. By transmitting more of the visible light, it also allows the use of less lighting energy. However, to accomplish this lower energy usage, either
photosensors at the working level or manual shutoff of lights must be used. See LI #1 (p 15).

Since the windows are high above the floor, the lower heat blockage is not a severe problem like it would be in an office building, as the higher heat gain would remain in the upper parts of the building in the monitor areas, well above the working level, where it could be removed by properly sized exhaust fans. The key to success here is to minimize the solar load at the working level to minimize the effect of heat on the workers in the summertime, while still providing enough natural light so that less electric energy can be used for the lighting.

4.3.2.3  Savings

**Conventional Window Film:**
Using reflective film, the percentage of solar energy typically transmitted through the glass is 44 percent. The percentage of daylight transmitted is 37 percent. Savings are calculated as:

\[
\text{The heat gain in the summertime will be reduced by } [1.17 \times (1.00 - 0.44)] \text{ Btu/sq ft/°F x 70,000 sq ft x (91 - 80)°F x 5 months/yr x 23 days/month x 8 hrs/day / 3413000 Btu/MWh = 136 MWh / yr.}
\]

There is no cost savings associated with the decrease of the heat gain, since the plant is not air-conditioned. However, the difference in temperature at the floor level due to the decrease in the heat gain from the sun should minimize or eliminate the need for additional 15 minute breaks, increasing employee productivity. Assuming that the additional morning break could be eliminated, and the afternoon break shortened, the savings would be:

\[
180 \text{ men x 0.33 hr/day x 20 days/yr x $60/hr} = $70,000.
\]

**Spectrally Selective Window Film:**
With this type of film, the percentage of solar energy transmitted is 45 to 50 percent, while the daylight transmitted can be as high as 70 percent.

Using the above calculations for conventional window film, the savings from the reduced break time would be the same $70,000.
In addition, because of the better light transmittance, the electric lighting could be reduced with a concurrent saving of approximately $2300/yr.

Further, the spectrally selective glass would allow the workers to see outside as though there were no barrier, contributing to a sustained sense of health and productivity.

Total savings are $72,300/yr.

4.3.2.4 Investment

**Conventional Window Film:**
The installed cost for a project of this size would be approximately $4.00/sq ft.

With approximately 70,000 sq ft of window area, the total investment would be $280,000.

**Spectrally Selective Window Film:**
The installed cost would be approximately $9.00/sq ft = $630,000.

4.3.2.5 Payback Calculation

The calculated payback (obviously not a cost-effective solution) is:

**Conventional Window Film:**
$280,000 / $70,000 = 4.0 yrs

**Spectrally Selective Film:**
$630,000 / $72,300 = 8.7 yrs.

Spectrally selective film is more suited for office buildings, schools, store windows, etc., but it was analyzed to show the difference, as spectrally selective film is becoming more of a factor in the marketplace. Further, you may want to analyze this type of window film in the future for other types of buildings, such as barracks, offices, etc.

NOTE: The “Savings” shown above are also included in HV #4 and HV #5. Because the investment in those ECOs is considerably less, and similar re-
sults would be achieved, those would be better solutions than window film. Further, installing the proper type and size of air circulating fans, would contribute to comfort of the workers thereby increasing their productivity even on days where they did not have to take extra breaks.

4.3.3 BE #3: Add Vestibule on West Side Door—Building 2233

4.3.3.1 Existing Conditions

In Building 2233 doors are opened throughout the day to allow for trucks needing maintenance to enter and exit and to allow travel of fork trucks that carry materials and parts between buildings. Mostly the doors at the ends of the building are used. Recently rapid roll-up doors have been installed on these two doors to reduce the time they are open (Figure 4). The door on the west end of the building gets the most use.

![Figure 4. Rapid roll-up doors in west side of Building 2233.](image)

When these doors are open in the winter large amounts of cold air enters the building. This causes cold areas in the building where it is hard to work and makes heating the building difficult.

It was also noted that there was an opening about one foot high above the door that ran the width of the door. This opening is also allowing cold air to enter the building in the winter.
4.3.3.2 Solution

A vestibule that is approximately 60 ft long by 25 ft wide could be added to the door opening on the west side. If room permits the vestibule would be outside the building. The existing door would be one end of the vestibule with a new door installed at the other end. Small vehicles and fork trucks would enter one end of the vestibule. The outside door would be shut after they had passed through and the inside door would open to allow entry into the building. This way there would be an air lock between the inside and outside of the building minimizing the amount of cold air that enters.

4.3.3.3 Savings

Adding this vestibule will reduce the amount of outside air infiltrating the building by 24,000 CFM when the door is open. Assuming the door is open 10 minutes/hour of operation, the annual energy savings is:

\[
Q = 1.08 \times 24,000 \text{ CFM} \times (64.4 - 39) \text{ °F} \times 10 \text{ min/hr} \times 9 \text{ hr/day} \times 140 \text{ days/yr} / 3413000 \text{ Btu/MWH} = 40.5 \text{ MWHth/yr}
\]

There is also an opening above the door that the vestibule would close thereby eliminating the infiltration of 2000 CFM:

\[
Q = 1.08 \times 2000 \text{ CFM} \times (64.4 - 39) \text{ °F} \times 6000 \text{ hrs/yr} / 3413000 \text{ Btu/MWH} = 96.5 \text{ MWHth/yr}
\]

The total energy cost savings is therefore $8,900 (6,800 €)/yr:

\[
\text{Cost Savings} = (40.5 + 96.5) \text{ MWHth/yr} \times 65/\text{MWH} = 8,905/\text{yr}
\]

4.3.3.4 Investment

The proposed vestibule would be 60 ft long by 25 ft wide, having an area of 1,500 sq ft. The estimated cost for such a vestibule is $70/sq ft, or $105,000 (81,000 €). The vestibule would be constructed of metal frame walls. Another rapid roll-up door would be required as would lighting in the new area.

4.3.3.5 Payback Calculation

The resulting payback of this project is 11.8 yrs.
4.3.4 BE #4: Use Light Shelves for Additional Natural Lighting—Building 2233

4.3.4.1 Existing Conditions

Figure 5 shows how the glass in the roof and windows along the sides of Building 2233 bring enough light into the building on a bright, sunny day during all seasons of the year so work can be performed without the use of electric lighting in the main area of the building. See ECM L1 #1 (p 15).

Figure 5. Light shelves in Building 2233.

The areas in the north side of the building do not have the availability of as much natural light as in the main part.

4.3.4.2 Solution

Install “light shelves” to bring the daylight further into the building on the north side. Light shelves are surfaces with reflective upper sides, located near the top of windows. They allow light to penetrate further into the building by reflecting some of the light off the ceiling, which allows the light to penetrate further into the building. This would allow the general space lighting to be put on photo sensors so they could be switched off
when there is enough light provided by daylight. The “task” lighting could still be on separate circuits and only shut off when not needed.

4.3.4.3 Comments

Light shelves are considerably more effective on the south and west sides of a building than the north side. After analysis, it was decided that this concept was not a cost-effective or even a viable solution for Building 2233, as it was not necessary for the main areas on the south and center of the building, and would not be an effective solution for the engine repair and other areas on the north side.

4.3.5 BE #5: Provide Insulated Panels for Door Openings—Building 2222

4.3.5.1 Existing Conditions

In Building 2222 there are eight bifold doors along the north side of the building. These doors are seldom used and have equipment and parts placed in front of them. These doors are approximately 17.5 ft wide by 12 ft high and appear to have approximately 1 in. of insulation providing a total insulating value of 0.21 Btu/sq ft/°F.

4.3.5.2 Solution

These door openings can be filled with an insulated removable panel to provide a greater resistance to heat loss. The proposed door panels would be fiber glass or metal covered foam sections the height of the door that are placed behind the existing doors. These door panels would be screwed together providing a smooth surface. Provisions will be made to allow easy disassembly if a door needs to be opened. The estimated new insulating value of the door with a panel is 0.09 Btu/sq ft/°F.

The door area should be inspected before these panels are installed and all cracks should be sealed or gasketed to provide a weather tight barrier. This will reduce the amount of cold air that infiltrates the building during the winter.

4.3.5.3 Savings

The estimated energy savings of these door panels is 9 MWHth/yr providing an annual cost savings of $585. The installation of the door panels will
also reduce the amount of outside air that enters to building providing an additional savings of 19 MWHth for a cost savings of $1,254/yr. Savings are calculated as:

\[
Q_{\text{Conduction}} = (0.21 - 0.09) \text{ Btu/sq ft/ \text{°F}} \times 1,680 \text{ sq ft} \times (64.4 - 39) \text{ °F} \times 6000 \text{ hrs/yr} / 3413000 \text{ Btu/MWH} = 9.0 \text{ MWHth/yr}
\]

\[
Q_{\text{Infiltration}} = 1.08 \times 400 \text{ CFM} \times (64.4 - 39) \text{ °F} \times 6000 \text{ hrs/yr} / 3413000 \text{ Btu/MWH} = 19.3 \text{ MWHth/yr}
\]

\[
Q_{\text{total}} = 28.3 \text{ MWHth/yr}
\]

\[
\text{Cost Savings} = (9.0 + 19.3) \text{ MWHth} \times \$65/\text{MWH} = \$1,840/\text{yr} (1,420 \text{ €})
\]

### 4.3.5.4 Investment

The total door area to be filled is 1,680 sq ft. Using a cost of $10/sq ft the total estimated installed cost is $16,800 (12,900 €).

### 4.3.5.5 Payback Calculation

The total energy savings is $1,840/yr resulting in a payback of the installation of these door panels of 9.1 yrs.

### 4.3.6 BE #6: Repair Door Seals—Building 2226

#### 4.3.6.1 Existing Conditions

In Building 2226, there are several doors that need repair so that they seal the door opening when they are closed. The openings caused by the damaged door frames allow cold air to infiltrate into the building in the winter. This causes cold drafts and increases the heating demand.

#### 4.3.6.2 Solution

Repair the door frames so that the door openings are properly sealed. Add seals and replace door panels where necessary.

#### 4.3.6.3 Savings

Approximately 200 CFM of outside air is estimated to enter the building due to these door leaks causing an energy use of almost 10 MWHth/yr. The annual energy cost of this additional heat is $630 (480 €). Savings are calculated as:

\[
Q = 1.08 \times 200 \text{ CFM} \times (64.4 - 39) \text{ °F} \times 6000 \text{ hrs/yr} / 3413000 \text{ Btu/MWH}
\]
\[ = 9.7 \text{ MWHth/yr} \]

The total energy cost savings is therefore $630 (480 €)/yr:

\[ \text{Cost Savings} = (9.7) \text{ MWHth} \times 65$/\text{MWH} = $630/\text{yr} \]

4.3.6.4 Investment

The estimated cost to repair each door is $1,000 for a total repair cost of $2,000 (1,540 €).

4.3.6.5 Payback Calculation

The resulting payback of repairing the doors is 3.2 yrs.

4.3.7 BE #7: Add Vestibule on West Side of Building Going-Up Ramp—Building 2371

4.3.7.1 Existing Conditions

Building 2371 is the major shipping facility at the depot. Here parts for a shipment are assembled from various warehouses onto pallets and placed in trailers for transport. On the west side of the building, one door is used in the route to the adjacent warehouses. As the result, this door is open a good percentage of the time and cold drafts are common in the adjacent area (Figure 6). This makes this space very uncomfortable in the winter and additional heat is used.
Figure 6. Door seals on Building 2226.

4.3.7.2 Solution

As you exit this door you proceed down a covered ramp to street level for traveling to nearby warehouses. This vestibule can be easily enclosed by adding walls and a door at the end. Then there will be doors at each end, which will be controlled such that one door will open to allow the fork truck to enter. Once the fork truck is inside the first door a will close and the second one will open. This air lock will minimize the cold air that enters the building.

4.3.7.3 Savings

It is estimated the vestibule will eliminate the infiltration by 12000 CFM (100FPM), which occurs an estimated 25 percent of the time. Savings are calculated as:

\[ Q = 1.08 \times 12,000 \text{ CFM} \times 0.25 \times (64.4 - 39) \text{ °F} \times 6000 \text{ hrs/yr} / 3413 \text{ MWH/Btuh} \]

\[ = 145 \text{ MWHth} \]

Energy cost savings = 145 MWHth X $65/MWHth = $9,404/yr (7,230 €)
4.3.7.4 Investment

The distance down the ramp is 84 ft. The width is 15 ft for an area of 1260 sq ft. Using a cost of $40/sq ft, the vestibule cost would be $50,400 (41,500 €).

4.3.7.5 Payback Calculation

The resulting simple payback of the vestibule is 5.4 yrs.

4.3.8 BE #8: Place Insulated Panel in Unused Door Areas—Building 2371

4.3.8.1 Existing Conditions

In Building 2371, there are six truck doors along the west side of the building are seldom used and have equipment and parts placed in front of them (Figure 7). These metal roll-up doors are approximately 12 ft wide by 10 ft high with no insulation. The estimated insulating value of a door is 1.11 Btu/sq ft/°F.

![Figure 7. Uninsulated, unused doors in Building 2371.](image)

4.3.8.2 Solution

These door openings can be filled with an insulated removable panel to provide a greater resistance to heat loss. The proposed door panels would be fiber glass or metal covered foam sections the height of the door that are placed behind the existing doors. These door panels would be screwed together providing a smooth surface. Provisions will be made to allow easy
disassembly if a door needs to be opened. The estimated new insulating value of the door with a panel is 0.09 Btu/sq ft/°F.

The door area should be inspected before these panels are installed and all cracks should be sealed or gasketed to provide a weather tight barrier. This will reduce the amount of cold air that infiltrates the building during the winter.

4.3.8.3 Savings

The estimated energy savings of these door panels is 32 MWHth/yr providing an annual cost savings of $2,112. The installation of the door panels will also reduce the amount of outside air that enters to building providing an additional savings of 19 MWHth for a cost savings of $1,254/yr. Savings are calculated as:

\[
Q_{\text{conduction}} = (1.1 - 0.09) \text{ Btu/sq ft/} {^\circ}\text{F} \times 720 \text{ sq ft} \times (64.4 - 39) {^\circ}\text{F} \times 6000 \text{ hrs/yr} / 3413000 \text{ Btu/MWH} = 32.5 \text{ MWHth/yr}
\]

\[
Q_{\text{infiltration}} = 1.08 \times 400 \text{ CFM} (64.4 - 39) {^\circ}\text{F} \times 6000 \text{ hrs/yr} / 3413000 \text{ Btu/MWH}
= 19.3 \text{ MWHth/yr}
\]

The total energy cost savings is therefore $3,367(2,590 €)/yr.

\[
\text{Cost Savings} = (32.5 + 19.3) \text{ MWHth} \times 65/\text{MWH} = 3,367/\text{yr}
\]

4.3.8.4 Investment

The total door area to be filled is 720 sq ft. Using a cost of $10/sq ft, the total estimated installed cost is $7,200 (5,500 €).

4.3.8.5 Payback Calculation

The total energy savings is $3,367/yr resulting in a payback of the installation of these door panels of 2.1 yrs.

4.3.9 BE #9: Repair Damaged Doors—Building 2371

4.3.9.1 Existing Conditions

In Building 2371 there are several doors that are damaged, allowing outside air to enter the building.
This is more serious in the winter than in the summer, as the wind velocity is higher and the cold drafts increase worker discomfort and increase heating demand.

4.3.9.2 Solution

Repair doors, including frames and seals as necessary.

4.3.9.3 Savings

Based on the conservative assumption that approximately 200 cfm of outside air/door enters the building due to door leaks, the additional energy use amounts to close to 10 MWh/yr. Savings are calculated as:

\[
1.09 \times 200 \text{ cfm} \times (64.4 - 39) \text{ °F} \times 6000 \text{ hrs/yr} / 3,413,000 \text{ Btu/MWh} = 9.7 \text{ MWh/yr}
\]

The cost savings = 9.7 MWh/yr x $65/MWh = $630/yr/door

4.3.9.4 Investment

It is dependent on the damage to the door and the type and amount of repair required, but the estimated cost to repair most of the doors is approximately $1000.

4.3.9.5 Payback Calculation

The calculated payback will occur in:

The payback = $1000/$630 = 1.6 yrs.

4.3.10 BE #10: Insulate North Wall—Building 2371

4.3.10.1 Existing Conditions

The north wall of Building 2371 is an uninsulated block wall, 180 ft long and approximately 25 ft high.

The workers in the north end of the building commented that it is much colder there than in the other parts of the building, even though the HVAC system is newer there, and supposedly operating properly.
4.3.10.2 Solution

The HVAC system should be checked to make sure it is operating properly, both for the volume of air being distributed into the space and for the temperature rise through the coils.

The wall should be checked to ensure there are no leaks that allow excessive infiltration and repaired if necessary, especially where the wall meets the roof.

Insulating the wall with will considerably reduce the cold air from conduction and radiation in the wintertime.

The analysis is based on 3-in. thick pinned-in-place rigid board insulation, and no exterior covering, as there are no workers near that wall.

4.3.10.3 Savings

The energy savings of the insulated wall is 49.8 MWhth/yr, providing an annual cost savings of $3237. These calculations are conservative as they do not take into account the potential reduction in infiltration.

\[
Q = (0.308 - 0.06) \text{ Btu/hr/sq ft/F} \times 4500 \text{ sq ft} \times (64.4 - 39) \text{ °F} \times 6000 \text{ hrs/yr} / 3413000 \text{Btu/MWh} = 49.8 \text{ MWh/yr}
\]

Energy cost savings = 49.8 MWh x $65/MWh = $3237 / yr

4.3.10.4 Investment

The approximate total area of the wall is 4500 sq ft. The estimated cost to install the insulation is:

\[
4500 \text{ sq ft} \times $5.00/\text{sq ft} = $22,500.
\]

4.3.10.5 Payback Calculation

The calculated simple payback will occur in 7 yrs.
4.3.11 BE #11: Use Transparent Plastic Panels Behind Glass Windows—Building 2281

4.3.11.1 Existing Conditions

The windows are single pane about 12 ft above the floor and continuous along the north and south sides of the building. Single pane glass has a poor insulating value. This allows much heat to escape during the cold months and similarly allows a considerable solar load in the summer months leading to thermal problems within the building, i.e., too cold in the winter and too hot in the summer.

4.3.11.2 Solution

Inspect all windows to ensure there are no broken windows, loose glazing, space between the frames and the building, etc. Repair as required.

Install transparent plastic panels behind the existing glass windows, as close to the glass as possible so that a dead air space will be provided. These panels will allow almost as much light to enter the building as does the single pane glass, thus not increasing the usage of the electric lighting. By using a three-layer panel, as in BE #1, the resistance to heat loss and heat gain (heat gain not considered in the energy saving calculation since there is no mechanical air-conditioning) by 0.50 Btu/sq ft/°F. The combined insulating value of the glass plus the panel is 0.35 Btu/sq ft/°F.

4.3.11.3 Savings

Using this type of transparent panel behind the existing windows will reduce the heat loss through the windows by 70 percent, or 158 MWh/yr for an energy cost savings of $10,270/yr. Savings are calculated as:

\[
Q = \frac{(1.17 - 0.35) \text{ Btu/hr/sq ft/°F} \times 4312 \text{ sq ft} \times (64.4 - 39) \text{ °F} \times 6000 \text{ hrs/yr}}{3413000 \text{ Btu/MWh}} = 158 \text{ MWh/yr}
\]

Cost savings = 158 MWh/yr x $65 / MWh = $10,270/yr

4.3.11.4 Investment

The estimate cost to prepare the underside of the windows and to install the new panels is $15/sq ft or $64,680.
4.3.11.5 Payback Calculation

The resulting simple payback period is $\frac{64680}{10270} = 6.3$ yrs.

4.3.12 BE #12: Use Transparent Plastic Panels To Replace Roof Skylights—Building 2281

4.3.12.1 Existing Conditions

The roof is slightly pitched with two rows of single translucent panels (skylights) running the length of the building, with a total area of 3520 sq ft (Figure 8). These panels have no insulating value and are also very dirty, minimizing the amount of light allowed through.

![Figure 8. Roof skylights in Building 2281.](image)

4.3.12.2 Solution

Replace the existing panels with the same three-layer panels as in BE #1.

4.3.12.3 Savings

The heat loss will be reduced by 118 MWh/yr, leading to an energy savings of $7670/yr. Savings are calculated as:

\[
Q = (1.10 - 0.35) \text{Btu/hr/sq ft/°F} \times 3520 \text{ sq ft} \times (64.4 - 39)°F \times 6000 \text{ hrs} / 3413000 \text{Btu/MWh} = 118 \text{ MWhth/yr}
\]

Energy cost savings = 118 x $65 = $7670.
4.3.12.4 **Investment**

Removing the existing single pane panels and replacing them with triple pane panels is estimated at $20/sq ft or $70,400.

4.3.12.5 **Payback Calculation**

The resulting simple payback is 9.2 yrs.

**4.3.13 BE #13: Repair and Insulate Roof Building 2281**

4.3.13.1 **Existing Conditions**

The existing 18,700 sq ft roof, which has only a moderate pitch, is a wooden structure with no insulation and with numerous leaks. For purposes of calculation, without having gone up on the roof, 5/8-in. plywood with asphalt roll roofing and asphalt shingles are assumed.

4.3.13.2 **Solution**

Remove existing roofing material and install new roof with 2-in. insulation board (R=10).

4.3.13.3 **Savings**

The heat loss will be reduced by 372 MWhth/yr, leading to an energy savings of $24,180/yr. Savings are calculated as:

\[
Q = (0.40 - 0.08) \text{ Btu/hr/sq ft/°F} \times 18,700 \text{ sq ft} \times (64.4 - 29) \text{ °F} \times 6000 \text{ hrs/yr} / 3413000 \text{ Btu/MWh} = 372 \text{ Mwhth / yr}
\]

Energy cost savings = 372 x $65 = $24,180.

4.3.13.4 **Investment**

The cost to remove the existing roof and replace it is estimated to be $8.00/sq ft = $149,600.

4.3.13.5 **Payback Calculation**

The resulting simple payback is 6.2 yrs.
4.3.14 BE #14: Repair Door Seals—Building 2370

4.3.14.1 Existing Conditions

In Building 2370 there are several doors that need repair so that they seal the door opening when they are closed. The openings caused by the damaged door frames allow cold air to infiltrate into the building in the winter. This causes cold drafts and increases the heating demand.

4.3.14.2 Solution

Repair the door frames so that the door openings are properly sealed. Add seals and replace door panels where necessary.

4.3.14.3 Savings

Approximately 200 CFM of outside air is estimated to enter the building due to these door leaks causing an energy use of almost 10 MWHth/yr. The annual energy cost of this additional heat is $627 (482 €). Savings are calculated as:

\[
Q = 1.08 \times 200 \text{ CFM} (64.4 - 39) ^\circ F \times 6000 \text{ hrs/yr} \times 3413000 \text{ Btu/MHW} \\
= 9.6 \text{ MWHth/yr} \\
\text{Cost Savings} = 9.6 \text{ MWHth} \times 65/\text{MWH} = 627/\text{yr}
\]

4.3.14.4 Investment

The estimated cost to repair each door is $1,000 for a total repair cost of $2,000 (480 €).

4.3.14.5 Payback Calculation

The resulting payback of repairing the doors is 3.2 yrs.

4.3.15 BE #15: Insulate Roof in Maintenance Building #2226, Kaiserslautern

Heating system is connected to the district heating.

4.3.15.1 Problem

High heat losses due to the absence of roof insulation
4.3.15.2 Solution

Insulate the roof

4.3.15.3 Estimated Energy Saving and Costs

Existing insulation: \( u = 2 \text{ W/m}^2\text{K} \)
New insulation: \( u = 0.5 \text{ W/m}^2\text{K} \)
Area: \( 1,640 \text{ m}^2 \)
Mean outside temperature: \( 4 \degree \text{C} \)
Use: 8 h/d ; 5 d/w ; 200 d/yr (= 1,140 h/yr)
Energy costs: \$65/MWh

Energy losses with existing insulation:
\[
2 \text{ W/m}^2\text{K} \times 1,640 \text{ m}^2 \times (20-4) \text{ K} \times 1,140 \text{ h/yr} = 59.8 \text{ MWh/yr}
\]

Energy losses with new insulation:
\[
0.5 \text{ W/m}^2\text{K} \times 1,640 \text{ m}^2 \times (20-4) \text{ K} \times 1,140 \text{ h/yr} = 15.0 \text{ MWh/yr}
\]

Saving:
\[
(59.8 - 15.0) \text{ MWh/yr} \times \$65/\text{MWh/yr} = \$2,912/\text{yr}
\]

Cost of insulation:
\[
\$20/\text{m}^2 \times 1,640 \text{ m}^2 = \$32,800
\]

Payback:
\[
\$32,800 / \$2,912/\text{yr} = 11.6 \text{ yrs}
\]

4.3.15.4 Problem

High heat losses due to the absence of roof insulation.

4.3.15.5 Solution

Insulate the roof.

4.3.15.6 Estimated Energy Saving and Costs

Existing insulation: \( u = 2 \text{ W/m}^2\text{K} \)
New insulation: \( u = 0.5 \text{ W/m}^2\text{K} \)
Area: \( 1,640 \text{ m}^2 \)
Mean outside temperature: \( 4 \degree \text{C} \)
Use: 8 h/d ; 5 d/w ; 200 d/yr (= 1,140 h/yr)
Energy costs: \$65/MWh

Energy losses with existing insulation:
\[
2 \text{ W/m}^2\text{K} \times 1,640 \text{ m}^2 \times (20-4) \text{ K} \times 1,140 \text{ h/yr} = 59.8 \text{ MWh/yr}
\]

Energy losses with new insulation:
\[
0.5 \text{ W/m}^2\text{K} \times 1,640 \text{ m}^2 \times (20-4) \text{ K} \times 1,140 \text{ h/yr} = 15.0 \text{ MWh/yr}
\]
4.3.15.7 Savings

\[(59.8 - 15.0) \text{ MWh/yr} \times \$65/\text{MWh/yr} = \$2,912/\text{yr}\]

4.3.15.8 Cost of Insulation

\[\$20/m^2 \times 1,640 \text{ m}^2 = \$32,800\]

4.3.15.9 Payback

\[\$32,800 / \$2,912/\text{yr} = 11.6 \text{ yrs}\]

Table 6 lists the ECM envelope (BE) summary for the Kaiserslautern buildings.

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings MWh/yr</th>
<th>Thermal Savings MWh/yr $$/yr</th>
<th>Additional Savings $$/yr</th>
<th>Total Savings $$/yr</th>
<th>Investment $$</th>
<th>Simple Payback yrs</th>
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Note: 1 Concept BE2a is recommended as more cost effective
2 Concept BE4 is not cost effective
4.4 Kaiserslautern Compressed Air System (CA)

4.4.1 CA #1: Turn Off Air Compressors on Weekends and Nights—Building 2224

4.4.1.1 Existing Conditions

The air compressors in Building 2224 are two Kaeser CS91, running at 7.5 bars. The compressors were logged during 2 days during the assessment week. Together with measuring the current (Amps) and measuring time in loaded and unloaded mode respectively, it was observed that only one compressor was in use during those 2 days, compressor No. 2. They are probably shifted as first priority machines every week. In unloaded mode the compressor uses 48 A and when loaded 103 A. At 400 V and cos $\phi$ of 0.85 (assumed) this corresponds to 28 kW and 61 kW respectively. The machine runs approximately 50 percent loaded and 50 percent unloaded, 24 hrs/day, 7 days/week. It never shuts off completely, although (in normal conditions) no work is done at night or on weekends.

4.4.1.2 Solution

Run the compressor weekdays 0600 to 1800, or about 60 hrs/week. Shut off compressors, manually or by programmable timer with week-long function, during nights and weekends. At emergency or over-time shifts the compressors can be started manually. Check so that no equipment needs the pressure 24/7 so that no damage is caused (can be done in Phase II of the energy assessment).

4.4.1.3 Savings

By being very conservative, assuming that the compressor that is operated is running 75 percent unloaded and 25 percent loaded to cover the leaks in the compressed air system in nights and weekends, the savings from shutting the compressor off are calculated as:

$$\text{Savings} = (0.25 \times 61 + 0.75 \times 28) \text{kW} \times 108 \text{hrs/week} \times 52 \text{ weeks} = 203 \text{ MWh/yr}.$$  
$$\text{Savings} = 203 \text{ MWh/yr} \times $80/\text{MWh} = $16,200/\text{yr} \ (12,500 \text{ €/yr}).$$

4.4.1.4 Investment

Programmable timer, installed and programmed: $500. Checking that the pressure is not needed by some special, sensitive equipment: $1,000, in-
ternal time. If some unique equipment needs the pressure: consider installing a separate compressor as a standalone, specific task compressor rather than keeping the entire system under pressure, see savings calculation above.

4.4.1.5 Payback Calculation

The calculated payback will occur within 2 months.

4.4.1.6 Comments

Further savings can be obtained by a systematic and policy-based effort to reduce as much of the compressed air-driven tools and machines as possible. With an overall efficiency of normally only 4 percent, the use of compressed air is the most expensive way someone can choose to perform mechanical work or operations. Electrically driven tools are much more efficient.

4.4.2 CA #2: Use Tools Operated by Electric Power Rather Than Compressed Air

4.4.2.1 Existing Conditions

Existing power tools are operated by compressed air, with pneumatic hoses strung along walls, columns, etc. Compressed air is provided by two air compressors located in a specific-use building (2224), which houses only the air compressors, and is a considerable distance away. It is known that up to 90 percent of energy used to compress air is wasted and is discharged as heat. Further, leaks in the system waste energy and can account for up to 30 percent of a compressor’s output.

Based on run time of the compressors when no work is being performed, e.g., in the evenings, there is a considerable amount of air leakage in the system. See CA #2 (p 59) for additional information relative to the air compressors themselves.

4.4.2.2 Solution

Replace the pneumatic tools with electric tools. Electric tools today are actually more powerful and have more torque than typical pneumatic tools.
Further, most electric tools are now available battery-operated, with almost the same torque characteristics as electric-driven.

The one potential downside to electric tools is that they are heavier than pneumatic tools. This is beyond the scope of an energy audit and would have to be evaluated by the production staff.

4.4.2.3 Savings

Based on the above comments and the information in CA #1, there should be considerable energy and cost savings by eliminating the operation of the compressors. The calculation of the actual savings is beyond the scope of this Level 1 audit, but should be considered in a Level 2 audit.

4.4.2.4 Investment

The investment should be only the cost of the electric tools, since there should be ample electrical capacity available to handle the minimal power requirements of the electric tools, unless there were certain tools in certain areas that needed to remain pneumatic. In that case, a small air compressor could be installed in that area (or those areas).

4.4.2.5 Payback Calculation

It is estimated that the payback, if an air compressor for local specific use did not have to be installed, would be less than 1 yr. Example cost comparison for electric vs. pneumatic 1/2-in. impact wrench is:

- Electric $270
- Pneumatic $100.

Table 7 lists the compressed air (CA) ECM summary for Kaiserslautern.

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings MmWh/yr</th>
<th>$k/yr</th>
<th>Thermal Savings MmWh/yr</th>
<th>$k/yr</th>
<th>Additional Savings $k/yr</th>
<th>Total Savings $k/yr</th>
<th>Investment $k</th>
<th>Simple Payback yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA1</td>
<td>Turn Off Air Compressors on Weekends and Nights</td>
<td>203</td>
<td>16.2</td>
<td></td>
<td></td>
<td></td>
<td>16.2</td>
<td>1.5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Building 2224</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA2</td>
<td>Use tools operated by Electric Power Rather than Compressed Air</td>
<td>When being replaced or when buying new ones</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt; 1 yr</td>
</tr>
</tbody>
</table>
4.5 Kaiserslautern Electrical (EL)

4.5.1 EL #1: Switch Off Computers When Not in Use—Building 2233

4.5.1.1 Existing Conditions

All computers in the area are on always as IT support suggests to facilitate software updates and back-up runs. Screens are switched off for the night in offices, but in the maintenance areas, it is likely that the screens are on always.

In 2233 there are about 15 PCs with flat screens in the offices and about 20 with ordinary monitors in the maintenance areas.

4.5.1.2 Solution

Activate power-save features or switch computers off when not in use. The power saving settings will allow to switch off screen or hibernate the hard disk.

Updates and backups can be programmed to take place when the computer is switched on or during the lunch break.

4.5.1.3 Savings

The saving has been calculated assuming that a computer with 17-in. or 19-in. monitor is using 150W when the screen is on and that a PC in stand-by mode in night-time with flat screen turned off is using 50W.

The weekly power on time for the computers will be reduced from 168 hrs to 50 hrs. Savings are calculated as:

\[
\text{Savings} = 35 \times (168 - 50) \text{ hrs/week} \times 52 \text{ weeks/yr} \times 100 \text{W} = 21,476 \text{kWh/yr} \\
\text{Savings} = 21,476 \text{kWh/yr} \times 1 \text{KW/1,000W} \times \$80 / \text{MWh} = \$1,718 / \text{yr} (1,321 \text{€/yr})
\]

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.5.1.4 Investment

No investment is required; most computers already have the possibility for power saving. New advice and instructions from IT support are needed.
4.5.1.5 **Payback Calculation**

There will be zero payback time.

Table 8 lists the electrical (EL) ECM summary for Kaiserslautern.

<table>
<thead>
<tr>
<th>ECM Description</th>
<th>Electrical Savings MmWh/yr</th>
<th>$k/yr</th>
<th>Thermal Savings KmWh/yr</th>
<th>$k/yr</th>
<th>Additional Savings $k/yr</th>
<th>Total Savings $k/yr</th>
<th>Investment $k</th>
<th>Simple Payback yrs</th>
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</thead>
<tbody>
<tr>
<td>Switch off Computers When Not In Use — Bldg 2233</td>
<td>36.8</td>
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</tbody>
</table>

### 4.6 Kaiserslautern HVAC

#### 4.6.1 HV #1: Improve Building Heating Controls

##### 4.6.1.1 Existing Conditions

At KAD (and Pirmasens) most of the HVAC systems are operated manually. The personnel in the buildings turn heaters on or off depending on their feelings regarding the indoor temperature. With many heaters in a big warehouse and with many persons working in the warehouse it is not likely that the heaters work uniformly to reach a normal setpoint regarding temperature. Only a few buildings have computerized, automatic control systems. and if they have, it is not certain that they work properly, see HV #240 (p 80) and HV #26 (p 101).

Thermostats are not always installed; in those cases the heaters are just switched on and off (e.g., HV #262 in Building 2281 [p 9180]). If thermostats are installed, these may be manipulated by the personnel, see HV #13, Building 2222 (p 79).

##### 4.6.1.2 Solution

This is not to suggest a total modernization of the building heating controls; this is not the one and only solution. Modern and computerized (centralized) systems need to be maintained, supervised, and understood by the people (Federal employees or contractors) who must successfully perform the automated tasks.
However, the following, general measures are proposed:

- One or several thermostats must be installed in every building that has heaters to provide comfortable indoor temperature.
- Each thermostat shall control one or several heaters, maybe with different temperatures in different areas (might be different materials or goods that does require different conditions).
- Thermostats shall be placed in locked “cages” that can only be operated by the supervisor, who will have the key.
- Thermostats should be of the kind that allows one setpoint during working hours and another at nights and weekends.

4.6.1.3 Savings

Savings come from more uniform indoor temperatures, less energy wasted due to overheating to meet the comfort levels of isolated individuals, improved productivity with more even climate. It is difficult to say how big the savings are on this general level, but the proposal regarding 2222, which is specific, indicates energy savings of around 20 percent. However, every building is unique; unless temperatures and energy use are logged, it is not possible to calculate potential general savings.

4.6.1.4 Investment

Very moderate investments are necessary to gain control of the waste of energy that comes from being out of control of the important parameters, i.e., the heating of buildings and to what temperatures.

4.6.1.5 Payback Calculation

The calculated payback will occur within months (winter months).

4.6.2 HV #2: Install Exhaust Fans for Ventilation—Building 2233

4.6.2.1 Existing Conditions

One hundred and eighty employees work in Building 2233. The building was built in 1952 and has large areas of glass in the roof and the walls. During the summer the indoor temperature rises to very high levels. To reduce the indoor temperature both doors at the east and west entrances are opened, but this is not sufficient, since the building itself works as a “greenhouse.” During some days every summer (that exact number is not
documented since it varies according to the outdoor temperature and the solar heat), the workers are allowed extra breaks, 2 * 15 min/day.

4.6.2.2 Solution

Either of these two solutions is proposed:

1. Install multiple exhaust fans of about 20,000 m³/h each (12,000 cfm). With an approximate building volume of 160,000 m³ it would probably be sufficient with 10 such exhaust fans, at the roof.

2. Install two large prop fans at the ceiling level in the east and west walls respectively, to exhaust hot air at the very ends of the building. If this is not sufficient (CFD studies could be performed to evaluate different solutions) it might become necessary also to install one or more roof exhaust fans at the centre of the building.

No matter which solution that is finally chosen, exhaust fans should be operated with at least the west and east end doors open. Exhaust fans should be temperature controlled, with respect to both indoor and outdoor temperatures. In other words, they should only be running when the outdoor temperature is higher than +20 °C AND/OR if the indoor air temperature is higher than +23 °C AND ONLY if the district heating system (and hot water circulating in the pipes) is completely shut off.

4.6.2.3 Savings

Avoiding extra breaks 20 days per summer yields calculated savings of:

\[
\text{Savings} = 180 \text{ employees} \times 2 \times 1/4 \text{hr} \times \$64.8/\text{hr} \times 20/\text{yr} = \$116,640/\text{yr} (90,000 \text{ €})
\]

In addition, expected savings from increased worker productivity would accrue from the improved work climate (by correcting the current “sauna” conditions), and by eliminating the extra breaks. However, measurements of increased productivity is beyond the scope of this stage of assessment.

4.6.2.4 Investment

The cost to purchase and install 10 exhaust fans with controls will be approximately $65,000 (50,000 €).
4.6.2.5  Payback Calculation

The estimated payback will occur during the first 12 hot summer days that the extra breaks are avoided (increased productivity unaccounted for).

4.6.3  HV #3: Install Destrafication Fans to Recover Heat in Upper Strata—Building 2233

4.6.3.1  Existing Conditions

In Building 2233, high up at platform level close to the glass roof, there are some fans installed with the purpose to bring warm air down from the higher levels down to the working space, the occupancy zone, in the winter. Even with these fans in operation, the indoor temperature does not exceed +5 to +8 °C when the outdoor temperature is –10 °C. At 0 °C outdoors the indoor temperature reaches no more than +12 to +15 °C. Of course, these are not satisfying working conditions. The installed fans quite obviously cannot work very well, for several reasons:

- They are too small with respect to capacity (air flow) and air velocity.
- No ducts support the down-going air stream; this might help some, although how much is not certain.
- The installed fans do not seem to be designed for this purpose; they appear to have been taken “off the shelf” from a stock of left-over fans.

4.6.3.2  Solution

Possible solutions include:

1. Replace the existing fans with new fans, with higher design pressure and with some meters of ductwork vertically from the fan and down, just as far down as the crane allows it. The new fans must also have the capacity to transport much larger volumes of warm air down to the occupancy level than the existing ones.
2. A second alternative would be to install a Dirivent system, with a network of small dimension circular ventilation ducts (80 – 100 mm) and with nozzles at the end. This system works with very high air speed, makes large volumes of warm air eject into the jet flow from the nozzle, and moves the air around and down to the floor level.
3. A third and perhaps better alternative (if the previous measure, HV #4, is implemented) would be to use the new summer exhaust fans in the winter as well to blow air down to the floor level. Additional investment
costs will then be in the controls, in some ductwork and with automatically controlled dampers that “know” if it is summer or winter.

4.6.3.3 Savings

The savings could probably be calculated as in HV #2 [4] above, but with the extra breaks for the workers to warm up instead of cooling down and with improved productivity also in this situation where it is possible to reach more uniform, close to 18–20 °C, indoor temperature.

Also, substantial energy savings can be counted upon from not having the heaters (a total of 60 unit heaters spread over the building area) running at maximum capacity as soon as it gets cold, without ever reaching the set-points. Since annual energy use for heat in this building alone is 7,000 MWh (over 430 kWh/m²/yr), a good deal of money could be invested to reduce the energy bill. Regardless whether the heating system is converted to IR-heaters; the energy savings from getting the heat down from the ceiling level are enormous (savings of at least 10%):

Cost Savings: 700 MWh/yr * $65/MWh = $45.5 K/yr

4.6.3.4 Investment

An investment in six new fans, at 20,000 m³/h each, will cost around $40,000, installed with controls. Additional investment in case the summer exhaust fans are installed: $20,000 (15,000 €)

4.6.3.5 Payback Calculation

$40,000 / $45,500/yr = 0.9 yrs

4.6.3.6 Comments

The existing fans must be removed. They can be used in another building, with lower ceiling. An example would be in a warehouse like 2371 or 2281 where it is also likely that warm air can be transported from the ceiling down to the occupancy zone.

The study of the Kieback & Peter HVAC control system showed that space temperature in Building 2233 is measured at floor level and at the ceiling level. With an outdoor temperature of +12.5 °C the average temperature at
floor level was +18 °C and the temperature at the ceiling level (uncertain on at what height the temperature sensors are placed) were at an average of over +27 °C. This indicates that transporting warm air from the ceiling level to the occupancy zone really has a great potential and that this proposal makes sense.

4.6.4 HV #4: Replace fans and Lengthen Duct on Heat Recovery Unit for Dynamometers #1 to #3

4.6.4.1 Existing Conditions

There are four test stands in Building 2233 that are used to test engines to be installed into Humvee vehicles. Each test lasts about 2 hrs. Cooling water from a cooling tower is used to cool the dynamometer brake and the engine radiator. Energy is also exhausted outside in the hot combustion gases. The annual fuel consumption is 460 MWh/yr for the four test cells, which if divided by 240 working days gives a fuel use per day of 1.9 MWh/day. The theoretical fuel input capacity for a Humvee motor is around 900 kW, the test uses about 92 percent of this use. For a Humvee diesel engine, approximately 60 kW is directed to the radiator, 180 kW is consumed by the brake and 200 kW of energy goes up with the exhaust gases. The rate of energy use of 440 kW/hour suggests the dynamometer are testing about 50 percent of the time.

For three of the dynamometers there is a heat recovery unit that uses the radiator heat to heat air that is blown into the building (Figure 9). This unit is not used much due to the noise made when in operation. The fourth dynamometer sends all its waste heat to a cooling tower for removal.
4.6.4.2 Solution

About 10 percent heat is released from dynamometer operations to the room by convection and radiation losses; the other 90 percent is evenly divided between work to the brake, exhaust gases, and heat removed by the radiator water. The total annual value of the fuel consumed is $29,900. This implies that there is a waste heat flow of approximately $9,000 in the exhaust gases, radiator water, and brake cooling water. If there is a use of this heat for half a year and 60 percent is obtainable from the waste stream, this represents an energy savings of $2,700/yr.

To recover heat from the exhaust gases, four heat recovery units would be required each about 3,000 CFM, for which the cost of each would approach $20,000 installed. This provides an unfavorable payback of almost 30 yrs.

The only practical project to recover some of this energy is to use the existing heat recovery system that has the noise problem. The air discharge of the unit could be reconfigured by adding more duct to act as a silencer and blow the tempered air into the building at another location. The fans could also be changed if necessary.

4.6.4.3 Savings

Recovery of heat from the radiator water can be a benefit for half the year. This heat recovery unit services three of the four dynamometers. It is esti-
mated 70 percent of the available heat is recoverable. The resulting savings is $2,360 (1,800 €)/yr. Savings are calculated as:

\[ \text{Energy cost savings} = 9,000 \times 0.5 \times 0.75 \times 0.7 = 2,360/\text{yr.} \]
\[ \text{Energy savings} = 2,360/ \text{$65/MWh} = 36.3 \text{ MWh/yr} \]

4.6.4.4 Investment

The cost to accomplish the modifications to the existing heat recovery unit should not exceed $12,000 (9,200 €).

4.6.4.5 Payback Calculation

The simple payback is 5.1 yrs.

4.6.5 HV #5: Replace Heating System for the Hot Water Radiant Heating System in Maintenance Building #2233, Kaiserslautern

Heat exchanger station and main distribution are in good conditions.

4.6.5.1 Problem

Inefficient heating during winter time. Secondary hot water distribution system is very old, and its left side is not insulated. Some very old air heaters are used and connecting pipes to some of them are not insulated.

4.6.5.2 Solution

Replace warm air heaters with hot water radiation panels. Install central controls of magnetic valves for the secondary hot water distribution system. Insulate hot water piping.

4.6.5.3 Estimated Energy Savings and Costs

Area: 14,900 m²
Heating: 6,060 MWh
Energy savings per year: 25%
Energy costs: $65/MWh

4.6.5.4 Savings

6,060 MWh * 25% * $65/MWh = $98,475/yr
4.6.5.5  Cost

Installation of heat radiator panels

- Panels 745 pieces (3m length) * $525/panel = $391,125
- Piping 1,000 m * $62.5/m = $62,500
- Design $1,250/d * 5d = $6,250
- Total Cost: $459,875
- Payback: $459,875/ $98,475/yr = 4.7 yrs

4.6.6  HV #6: Reduce Excessive Air Use—Welding and Vehicle Exhaust Building

4.6.6.1  Existing Condition

The exhaust fans for the welding and vehicle exhaust areas run continuously during all shifts, even when there is no requirement for them to be in use.

4.6.6.2  Solution

Install dampers at individual stations to reduce the amount of total system air required when those stations are not in use. Install variable speed drives (VSD) at each exhaust fan, which would sense lower airflow requirement by means of signals from pressure sensors. VSD will then slow fans down to meet new airflow and pressure requirements. Exhaust air would always be available, as fans would be continuously running during all shifts, but the fans would be using only as much energy as would be required for the amount of exhaust air needed at any particular time.

4.6.6.3  Savings

The energy used by a variable torque fan varies as the cube ratio of the speed. As a fan slows down, the energy use decreases by (rpm1/rpm2)^3. Thus, if only half the air is required at a particular time, the energy used by the fan would theoretically be (1/2)^3, or 1/8 the original power.

In actuality, because of windage, bearing, and inertia losses, this number is closer to 20 percent than 12.5 percent, but is still a considerable energy and cost saving.
Using the example of a 20 HP motor, and assuming the air requirement during an 8-hr shift would be 40 percent on the average, the energy used by the fan would theoretically be $0.40^3$, or 0.06 of the full load energy. In actuality, it would be more like 0.10. Savings are calculated as:

The energy use for the 20 HP motor in this example, assuming the existing motor is 80% loaded, would be $20 \times 0.80 \times 0.746 \times 16 \times 250 = 47,744 \text{ kWh/yr}$

The energy use with a VSD would be $0.1 \times 0.746 \times 16 \times 250 = 298 \text{ kWh/yr}$

The energy savings would be $47,744 - 298 = 47,446 \text{ kWh/yr}$.

The energy cost savings would be $47,446 \times 0.08 / \text{kWh} = $3796 / \text{yr}$.

4.6.6.4 Investment

The size of all exhaust fan motors in use at the time of this audit were not ascertained. Using a 20 HP motor as an example, the installed cost of a VSD to replace the existing starter and disconnect would be approximately $3500. Assuming that an average of four dampers are required for each exhaust system, the installed cost would be approximately $4000 for the dampers and controllers.

4.6.6.5 Payback Calculation

The calculated payback will occur in:

\[
\frac{7500}{3796} = 2.0 \text{ yrs}
\]

4.6.7 HV #7: Replace Warm Air Heaters with Hot Water Radiant Panels at Warehouse, Building #2213

The roof and walls are well insulated.

4.6.7.1 Problem

Warm air heaters are not efficient.

4.6.7.2 Solution

Replace warm air heaters with hot water radiation panels.

4.6.7.3 Estimated Energy Savings and Cost

Area: 950 m²
Heating: 380 MWh.
Energy savings per year: 25%
Energy costs: $65/MWh
Saving: 380 MWh * 25% * $65/MWh = $6,175/yr

4.6.7.4 Cost

Installation of heat radiator panels

- Panels 48 pieces (3m length) * $525/panel = $25,200
- Piping 60m * $62.5/m = $3,750
- Design $1,250/d * 4d= $5,000
- Total cost: $33,950

4.6.7.5 Payback

$33,950/ $6,175/yr = 5.5 yrs

4.6.8 HV #8: Replace Warm Air Heaters with Hot Water Radiant Panels at Warehouse, Building #2219

Roof and walls are well insulated.

4.6.8.1 Problem

- Warm air heaters are not efficient.
- Ventilation flaps and facade are not tied

4.6.8.2 Solution

- Replace warm air heaters with hot water radiation panels
- Install new flaps

4.6.8.3 Estimated Energy Savings and Cost

Area: 3,040 m²
Heating: 960 MWh.
Energy savings per year: 25%
Energy costs: $65/MWh
Saving: 960 MWh * 25% * $65/MWh = $15,600/yr
4.6.8.4  Cost

Installation of heat radiator panels:

Panels 152 pieces (3m length) * $525/panel = $79,800
Piping 190 m * $62.5/m = $11,875
Design $1,250/d * 5d= $6,250
Total cost: $97,925

4.6.8.5  Payback

$97,925/ $15,600/yr = 6.3 yrs

4.6.9  HV #9: Recirculate Exhaust Air Back into Booth during Drying Operations—Building 2225

4.6.9.1  Existing Conditions

The main paint booth located in Building 2225 uses 100 percent outside when ever it is operating. In the winter time, this air must be heated to 70 °F (21 °C) for a proper paint and drying temperature. Outside air is needed when parts are being painted and during the flash-off period after painting to keep the solvent fumes under control, but during the part drying period in the booth, there is little solvent being released to the atmosphere and most of the exhaust air can be recirculated.

4.6.9.2  Solution

To achieve this recirculation of oven air place, a new duct between the exhaust air discharge duct and the air intake to the booth’s supply air units. There will be dampers placed in the new connection duct as well as after the connection in the exhaust duct. When the paint booth’s operation switches to drying, the damper in the exhaust duct will partially close and the damper in the connect duct will open allowing 70 percent of the exhaust air to be recirculated.

4.6.9.3  Savings

The estimated air flow in this paint booth is 24,000 CFM, which can be recirculated an estimated 15 hrs/wk or 360 hrs during the heating season
each year. The estimated heating energy savings is 59 MWh/yr. Savings are calculated as:

\[
Q = 1.08 \times 24,000 \text{ CFM} \times 70\% \times (70 - 39) ^\circ\text{F} \times 360 \text{ hrs/yr} / 3413 \text{ MWH/Btuh}
\]

\[
= 59 \text{ MWHth}
\]

Energy cost savings = 59 MWHth X $65/MWHth = $3,856/yr (2,970 €)

4.6.9.4 Investment

The estimated cost of the new dampers and duct connections is $20,000 (15,400 €).

4.6.9.5 Payback Calculation

The resulting payback is 5.2 yrs.

4.6.10 HV #10: Replace heaters, insulate roof and improve usage of the heat exchange station In Warehouse, Building #2238

4.6.10.1 Problem

Warm air heaters are not efficient. Excessive heat losses due to poor roof insulation. Central heating heat exchange station is over sized for this building

4.6.10.2 Solution

- Replace warm air heaters with hot water radiation panels
- Insulate roof
- Use heat exchanger station for other buildings
- Replace heating system

4.6.10.3 Estimated Energy Savings and Cost

Area: 1,850 m²
Heating: 540 MWh
Energy savings per year: 25%
Energy costs: $65/MWh

4.6.10.4 Savings

\[
540 \text{ MWh} \times 25\% \times $65/\text{MWh} = $8,775/\text{yr}
\]
4.6.10.5 Cost

*Installation of Heat Radiator Panels*

- Panels 92 pieces (3m length) * $525/panel = $48,300
- Piping 110 m * $62.5/m = $6,875
- Design $1,250/d * 5d = $6,250
- Total cost: $61,425

4.6.10.6 Payback

- $61,425/ $8,775/yr = 7.0 yrs

4.6.10.7 Insulate Roof

*Estimated Energy Savings and Cost*

- Existing insulation: u = 2 W/m²K
- New insulation: u = 0.5 W/m²K
- Area: 1,850 m²
- Mean outside temperature: 4 °C
- Use: 8 h/d ; 5 d/w ; 200 d/yr = 1,140 h/yr
- Energy costs: $65/MWh
- Energy loss with existing insulation: 2 W/m²K * 1,850 m² * (20-4) K * 1,140 h/yr = 67.5 MWh/yr
- Energy loss with a new insulation: 0.5 W/m²K * 1,850 m² * (20-4) K * 1,140 h/yr = 16.9 MWh/yr
- Savings: (67.5 – 16.9) MWh/yr * $65/MWh = $3,289/yr

Cost

- Cost of insulation: $20/m² * 1,850 m² = $37,000

Payback

- $37,000/ $3,289/yr = 11.2 yrs
4.6.11 HV #11: Replace Heaters and insulate the roof In Warehouse, Building # 2239, Kaiserslautern

4.6.11.1 Problem

Warm air heaters are not efficient. Excessive heat losses due to poor roof insulation.

4.6.11.2 Solution

Replace warm air heaters with hot water radiation panels, Insulate Roof

Connect the building to the central hot water system, e.g., to the existing heat exchange station at the building #2238.

Estimated Energy Savings and Cost

Heating System Replacement

Area: 2,780 m²
Heating: 830 MWh.
Energy savings per year: 25%
Energy costs: $65/MWh
Saving: 830 MWh * 25% * $65/MWh = $13,488/yr

Cost

Installation of heat radiator panels
Panels 139 pieces (3m length) * $525/panel = $72,975
Piping 170 m * $62.5/m = $10,625
Design $1,250/d * 5d= $6,250
Total cost: $89,850

Payback

$89,850 / $13,488/yr = 6.7 yrs

Roof Insulation

Estimated energy savings and cost

Old insulation: u = 2 W/m²K
New insulation: u = 0.5 W/m²K
Area: 2,780 m²
Mean outside temperature: 4 °C
Use: 8 h/d ; 5 d/w ; 200 d/yr (= 1,140 h/yr)
Energy costs: $65/MWh
Energy losses with existing insulation: 2 W/m²K * 2,780 m² * (20-4) K * 1,140 h/yr = 101.4 MWh/yr

Energy losses with new insulation
0.5 W/m²K * 2,780 m² * (20-4) K * 1,140 h/yr = 25.4 MWh/yr
Savings: (101.4 – 25.4) MWh/yr * $65/MWh/yr = $4,940/yr

Cost
Cost of $insulation:

20/m² * 2,780 m² = $55,600

Payback
$55,600 / $4,940/yr = 11.3 yrs

4.6.12 HV #12: Improve System Efficiency in Tire Repair and Masking
Area—Building 2255

4.6.12.1 Existing Conditions
The existing H&V units in this area are not operational, leading to lack of air movement all year and lack of heat in the cold weather. Because of this, additional time is required to mask and prepare vehicles before they enter the paint booth.

4.6.12.2 Solution
Two solutions were examined: radiant heating panels and repair of the existing systems. Radiant heating panels would be a more energy efficient way to provide heat in the cold weather; however, that type of system would do nothing to provide any air movement in the cooling season to make the workers more comfortable because of the evaporative cooling effect provided by air movement, which would make them more productive.
It was therefore decided that repair of the existing units and the ductwork, since they are already in place would be a more advantageous solution. Researchers could not discover why the existing units and ductwork had been decommissioned. The reasoning for this needs to be ascertained before a final decision is made.

4.6.12.3 Savings

The savings will occur in the increase in productivity, both from the personnel having to take fewer breaks in both the cold and hot weather, and from the decreased time to prepare vehicles to enter the paint booth. What this increase in productivity might be is beyond the scope of this study.

4.6.12.4 Investment

The cost of the retrofit is unknown without further study.

4.6.13 HV #13: Place Thermostat Controls Away from Occupants for Improved Control for Air Heaters—Building 2222

4.6.13.1 Existing Conditions

The research team noticed that it was very warm inside Building 2222. When two of the thermostats that control the unit heaters (supply from the district heating network) were checked, it was found that one thermostat had a setpoint of +24 °C both night and day and the second had a setpoint of +24 °C in daytime and +20 °C at night. The normal setpoint would be +20 °C during working hours and a lower setting, perhaps +17 °C at night and weekends. Heating the building to +24 °C wastes energy. The supervisor stated that the setpoint is supposed to be +20 °C in daytime.

4.6.13.2 Solution

Thermostats must be adjusted to both day- and nighttime setpoints. Locks should be purchased and installed so that only the supervisor can change the setpoints. This will prevent energy waste.

4.6.13.3 Savings

Building 2222 is approximately 1,400 m² (15,000 sq ft). With a normal annual energy use of around 300 kWh/m² this means 420 MWh of district
heating per year. By reducing the indoor temperature from +24 °C to +20 °C in daytime and to +18 °C in nights and weekends approximately 25 percent of the annual energy use can be saved, or 105 MWhth/yr worth $6,800/yr (5,200 €/yr).

4.6.13.4 Investment

The required investment will be no more than $200 (150 €).

4.6.13.5 Payback Calculation

The calculated payback will occur within days.

4.6.13.6 Comments

Since it is uncertain whether the thermostat settings observed by the research team represent the settings in operation for the entire winter, the calculated savings must be seen as “what if” calculations. However, the fact that such easy, “low hanging fruits” are available indicates that KAD personnel could improve attention to and awareness of energy costs.

4.6.14 HV #14: Increase Ventilation To Reduce Solvent Fumes in Space—Building 2222

4.6.14.1 Existing Conditions

In Building 2222 there is little ventilation air brought into the building and solvent fumes from cleaning transmission parts is very noticeable. Transmissions are tested in this building by placing them on a test stand that needs cooling to operate. At first glance it was thought that the heat being dissipated could be used to warm ventilation air to the building, but the quantity of heat is small and intermittent making it impractical for an energy source.

4.6.14.2 Solution

A ventilation unit having a heat exchanger could be installed to reduce the concentration of solvent fumes. Air would be exhausted through this unit and the heat in the warm exhaust air could be transferred to the incoming supply air.
4.6.14.3 **Savings**

There would be no energy savings with this project, but the workspace environmental condition would improve. The result may be a reduction in worker complaints and use of sick time. More evaluation of the conditions would be required to determine the extent.

4.6.14.4 **Investment**

The cost for a 10,000 CFM supply air unit with a heat recovery unit and a hot water coil would be about $40,000 (30,800 €).

4.6.14.5 **Payback Calculation**

There is no economical payback that can be determined, but the installation should be justified by the improved workspace conditions.

4.6.15 **HV 15: Replace Warm Air Unit Heaters with Hydronic Radiant Panels Heaters in Paint Shop, Building # 2225**

Building is connected to district heating.

4.6.15.1 **Problem**

Low efficiency of heating with unit air heaters

4.6.15.2 **Solution**

Replace warm air unit heaters with hot water radiant panels

4.6.15.3 **Estimated Energy Savings and Cost**

Area: 920 m²  
Heating energy used: 270 MWh  
Energy savings per yr: 25%  
Energy costs: $65/MWh  
Saving: 270 MWh * 25% * $65/MWh = $4,388/yr

4.6.15.4 **Cost**

Installation of heat radiator panels
Panels 45 pieces (3m length) * $525/panel = $23,625
Piping 50 m * $62.5/m = $3,125
Design $1,250/d * 4d= $5,000
Total Cost: $31,750

4.6.15.5 Payback

$31,750/ $4,388/yr = 7.2 yrs

4.6.16 HV #16: Provide Heaters over Doors on South Side—Building 2226

4.6.16.1 Existing Conditions

Building 2226 is used for large vehicle maintenance repair. These large vehicles enter the building through doors on the south side of the building. There are no door heaters to reduce the flow of outside air when these doors are opened. Also, the building heating system is not very effective since the heaters are located high in the building and have difficulty getting the warm air down to worker level.

4.6.16.2 Solution

Install two door heaters that can direct warm air down over the door opening when a door is raised. This will reduce the cold in the building when a door is opened.

4.6.16.3 Savings

There is no measurable energy savings with this system, but occupant comfort should be improved.

4.6.16.4 Investment

The cost for two door heaters should be about $100,000 (76,900 €).

4.6.16.5 Payback Calculation

There is no economical payback that can be determined, but the installation should be justified by the improved workspace conditions.
4.6.17 HV #17: Replace Warm Air Unit Heaters with Hydronic Radiant Panels Heaters in Maintenance Building # 2226

Heating system is connected to the district heating.

4.6.17.1 Problem

Low efficiency of heating with unit air heaters

4.6.17.2 Solution

Replace warm air unit heaters with hot water radiant panels

4.6.17.3 Estimated Energy Saving and Costs

Heaters Replacement

Area: 1,640 m²
Heating: 480 MWh.
Energy savings per yr with unit heaters replacement: 25%
Energy costs: $65/MWh
Saving: 480 MWh * 25% * $65/MWh = $7,800/yr

Cost of Radiant Panels Installation

Panels 80 pieces (3m length) * $525/panel = $42,000
Piping 100 m * $62.5/m = $6,250
Design $1,250/d * 5d = $6,250
Total cost: $54,500

Payback

$54,500/ $7,800/yr = 7.0 yrs

4.6.18 HV #18: Separate the Building Heating System from the Boiler and Connect the Building to District Heating System at Apprentice Shop, Building # 2364

4.6.18.1 Problem

Oversized oil heated boiler providing a low pressure steam for the building.
4.6.18.2 Solution

Separate the building heating system from the oil heated boiler and connect the building system to the district heating.

No information on energy consumption was available. Estimated energy savings: 25% by switching to district heating. Expected payback period is less than 5 yrs.

4.6.19 HV #19: Replace Warm Air Heaters with Hot Water Radiant Panels
Replace Heaters in Apprentice Shop, Building # 2363

4.6.19.1 Problem

Inefficient heating during winter time.

4.6.19.2 Solution

Replace warm air heaters with hot water radiation panels.

**Estimated energy savings and cost:**

Area: 1,150 m²
Heating: 300 MWh
Energy savings per yr: 25%
Energy costs: $65/MWh
Saving: 300 MWh * 25% * $65/MWh = $4,875/yr

**Installation of Heat Radiator Panels**

Panels 57 pieces (3m length) * $525/panel = $29,925
Piping 70 m * $62.5/m = $4,375
Design $1,250/d * 4d= $5,000
Total cost: $39,300

**Payback**

$39,300/ $4,875/yr = 8.1 yrs
4.6.20 HV #20: Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop, Building # 2372

4.6.20.1 Problem

Warm air heaters are used in combination with ventilation system. Additional need for mobile air heaters.

4.6.20.2 Solution

Re-commission existing ventilation system Replace warm air heaters with hot water radiant panels

4.6.20.3 Estimated Energy Savings and Cost

Area: 1,600 m²
Heating: 760 MWh.
Energy savings per yr: 25%
Energy costs: $65/MWh
Saving: 760 MWh * 25% * $65/MWh = $11,400/yr

4.6.20.4 Cost

Installation of heat radiator panels:
- Panels 80 pieces (3m length) * $525/panel = $42,000
- Piping 100 m * $62.5/m = $6,250
- Design $1,250/d * 4d = $5,000
- Total cost: $53,250

4.6.20.5 Payback

$53,250/ $11,400/yr = 4.7 yrs

4.6.21 HV #21: HV #22 [16]: Have Heating Utility Turn Off Heat to Buildings when not Warranted

4.6.21.1 Existing Conditions

It was apparent that many of the buildings were being heated unnecessarily by district heat because of a short cool spell that happened during the site visit. It may very well be that the district heating is in use on many occasions when it is not warranted.
4.6.21.2 Solution

Make sure that main heating valves are closed when heat to a building or an area is not required.

4.6.21.3 Savings

Actual savings will depend on the situation.

4.6.21.4 Investment

There is no investment required. Someone needs to be given the responsibility to decide whether or not heat is required, and to ensure it is not on when not required.

4.6.21.5 Payback Calculation

The calculated payback is immediate.

4.6.22 HV #22: Use Heat from Generator Test for Building Heat—Building 2362

4.6.22.1 Existing Conditions

Building 2362 is used to test portable electrical generators and in doing so needs a way to use the electricity created. This is done by heating up electrical coils in an air flow system. Air is passed through the electrical coils to cool them. In this system, outside air is passed through the system and discharged outside (Figure 10) with no benefit gained from this waste heat. Two systems (one at 500 kW, the other at 10 kW) perform this function.
4.6.22.2 Solution

The heat provided by the electric heating coil could be used by the building during the winter. This could be accomplished by adding a duct section that would redirect the heated air back into the building. Dampers would be installed to adjust the amount of heated air that would enter the building.

4.6.22.3 Savings

Using the 500 kW heating unit as the major heating source and assuming its loaded at 30 percent for half the time, savings are calculated as:

\[ Q = 500 \text{ kW} \times 0.5 \times 0.3 \times 40 \text{ hrs/week} \times 26 \text{ weeks/yr} = 78,000 \text{ kWh/yr} \]

Cost savings = 78 MWHth $65/MWH = $5,070/yr (3,900 €)

4.6.22.4 Investment

The cost for the duct extensions, an opening into the building and dampers with controls is approximately $15,000 (11,500 €).

4.6.22.5 Payback Calculation

The resulting payback period is 3 yrs.
4.6.23 HV #23: Provide Door Heater at Door on East Side—Building 2371

4.6.23.1 Existing Conditions

Building 2371 is used to ship parts for the Depot and it is occupied 24 hrs/day 7 days/week. Parts are gathered and taken to this building and assembled in their shipping containers for placement in a trailer. The trailers are stationed at shipping docks, which are open to the outside. The major dock can handle a number of trailers and thus the door opening into the building receives much fork truck traffic.

This door is open approximately 25 percent of the time to let a fork truck in or out. When open cold outdoor air enters the building creating cold drafts and making the space uncomfortable.

A vestibule is not considered for this application since the truck dock floor is a metal grading with many openings. There is also little room to place a vestibule structure and still maneuver fork trucks to all trailer locations.

4.6.23.2 Solution

Place a door heater at this door to reduce the outside air that enters the building. This door heater will also temper the air that does enter the building through the door.

4.6.23.3 Savings

The addition of a door heater on this door will reduce the amount of cold air entering the building. There will be an estimated 3,000 CFM reduction in the infiltration of outside air that would require heating. Savings are calculated as:

\[ Q = 1.08 \times 3,000 \text{ CFM} \times 25\% \times (64.4 - 39) \text{ °F} \times 6000 \text{ hrs/yr} / 3413 \text{ MWH/Btuh} = 36 \text{ MWHth} \]

Energy cost savings = 36 MWHth X $65/MWHth = $2,351/yr (1,810 €)

4.6.23.4 Investment

The approximate cost for a 12,000 CFM heater for this 10 x 12-ft door is $25,000 (19,200 €).
4.6.23.5 Payback Calculation

The resulting payback is 10.6 yrs.

4.6.24 HV #24: Provide Better Controls of H&V—Building 2371

This ECM has partly been discussed with Dieter Haertel, who expressed the belief that the control system works as it should in Building 2371. Nevertheless, the function of the system should be thoroughly checked, either in a Phase II assessment or by the system provider in teamwork with DPW and with the occupants of the building (that know how the indoor climate varies).

4.6.24.1 Existing Conditions

The heating and ventilation control system in the 2371 warehouse requires attention. Apparently, inaccurate information has been used to justify continuously running the AHUs (six air handlers at 33,500 m³/h each) on the basis that workers occupy the Building 24/7. In fact, only three people work the night shift, in the south section of the building—not justification to run the AHUs in the other two thirds of the building.

It was observed that the two AHUs in the northern section of the building were not running although this area was the coldest and where they were in most need for heat. On the other hand, in the other parts of the building the AHUs were running, although the indoor temperature had reached the various setpoints (as measured by us and as identified from the computer screen of the Kieback & Peter HVAC control system).

Apparently, temperature sensors have been mixed so that the AHUs operate on faulty signals, which do not correspond to the space they should heat and to ventilate.

The system clock was 1 hour wrong, which is immaterial for 24/7 operation. However, for more efficient operation (i.e., running only Section 3 24/7, and the other AHUs on weekdays 0500–1700 (unless for heating when a minimum night temperature of, say, +15 °C is reached), the clock must adjusted to reflect the correct time.
4.6.24.2 Solution

1. Check the function of the heating and ventilation controls. Make sure that they work properly
2. Consider controlling the supply air temperature according to measured exhaust air temperature, with supply air temperature on a curve between a maximum and a minimum temperature.
3. Run only two AHUs in Section 3 at night and on weekends. Run the remaining four AHUs only when needed to maintain a minimum temperature, at 100 percent return air, at night and on weekends.

4.6.24.3 Savings

The heat consumption in Building 2371 is 2,500 MWh/yr. That is approximately 250 kWh/m², yr. Minimizing the ventilation flow as suggested above, and night and weekend heating to only +15 °C, will save 365 MWh of electricity worth $29,000/yr and 600 MWh of district heat worth $39,000/yr, totally $68,000/yr (52,000 €/yr).

4.6.24.4 Investment

The required investment will include engineering time to check the controls, new controls to implement solution #2 and #3.

4.6.24.5 Payback Calculation

The calculated payback will occur immediately.

4.6.25 HV #25: Insulate Heating System Components—Building 2371

4.6.25.1 Existing Conditions

The district heating network enters at the south west corner of Building 2371. After the heat exchangers, some uninsulated pipes lead to unnecessary heat losses in the secondary system, and also to unnecessary high local temperatures due to heat losses from radiation and convection.

4.6.25.2 Solution

Insulate both supply and return pipes.
4.6.25.3  Savings

Since the size of the uninsulated part of the system is unknown, savings in this case cannot be calculated.

4.6.25.4  Investment

The required investment will be a few hundred dollars.

4.6.25.5  Payback Calculation

The calculated payback will occur within 2 yrs.

4.6.26 HV #26: Provide Temperature Control of Unit Heaters—Building 2281

4.6.26.1  Existing Conditions

Building 2281 is a warehouse with an area of approximately 6,000 m² (70,000 sq ft). The building is heated by a large number of unit heaters, supplied from the district heating network. The district heating comes in at the east end and goes all the way to the west end, after which it is distributed in the secondary system to all the unit heaters.

One of the most urgent problems to solve in this building (after the poor roof) is to correct the controls for the unit heaters. (They are currently switched on or off manually.)

4.6.26.2  Solution

At least six thermostats must be installed in the building. Each thermostat shall control a group of unit heaters, possibly with different temperatures in different areas (might be different materials or goods that does require different conditions). Thermostats shall be placed in locked "cages" that can only be operated by the supervisor, who will have the key.

Thermostats should be programmable, to allow one setpoint during working hours and another at night and on weekends. This will create uniform and stable space temperatures and a good working environment.
4.6.26.3 Savings

Because no recorded or logged data on indoor temperatures in the winter was available, savings for these improvements are hard to calculate. However, experience suggests that this kind of measure generally saves 10 percent of the heat consumption over a year. For Building 2281, assuming heat consumption in the region of 300 kW/m² yr (between the numbers of buildings 2371 and 2233), the savings then would be 180 MWh th/yr, or about $11,700/yr (9,000 €/yr).

4.6.26.4 Investment

The required investment will be about $7,000 (5,000 €).

4.6.26.5 Payback Calculation

Payback will occur within 7 months.

Table 9 lists the HVAC ECMs for Kaiserslautern.

### Table 9. Kaiserslautern AD HVAC ECM summary.

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings</th>
<th>Thermal Savings</th>
<th>Additional Savings</th>
<th>Total Savings</th>
<th>Investment</th>
<th>Simple Payback</th>
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<td>HV1</td>
<td>Improve Building Heating Controls</td>
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<td>Install Exhaust Fans To Ventilate Building 2233</td>
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<td>Install Destratification Fans Recover Heat in Upper Strata - Building 2233</td>
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<td>Replace fans and Lengthen Duct on Heat Recovery Unit for Dynamometers 1 to 3</td>
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<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2233</td>
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<td>Recirculate Exhaust Air Back into Booth During Drying Operations, Building 2225</td>
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<td>Replace heaters, insulate roof and improve usage of the heat exchange station in Warehouse, Building #2238</td>
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<td>HV13</td>
<td>Place Thermostat Controls Away From Occupants. Improved Control For Air Heaters</td>
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<td>HV18</td>
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<td>HV21</td>
<td>Have Heating Utility Turn off Heat to Buildings when not Warranted</td>
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<td>HV22</td>
<td>Use Heat from Generator Test for Building Heat, Building 2362</td>
<td>78</td>
<td>5.1</td>
<td>5.1</td>
<td>15.0</td>
<td>3.0</td>
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<tr>
<td>HV23</td>
<td>Provide Door Heater at Door on East Side of Building 2371</td>
<td>36</td>
<td>2.3</td>
<td>2.3</td>
<td>25.0</td>
<td>10.7</td>
<td></td>
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<tr>
<td>ECM</td>
<td>ECM Description</td>
<td>Electrical Savings</td>
<td>Thermal Savings</td>
<td>Additional Savings</td>
<td>Total Savings</td>
<td>Investment</td>
<td>Simple Payback</td>
</tr>
<tr>
<td>-------</td>
<td>------------------------------------------------------</td>
<td>--------------------</td>
<td>----------------</td>
<td>-------------------</td>
<td>---------------</td>
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<tr>
<td>HV24</td>
<td>Provide Better Controls Of H&amp;V In Building 2371</td>
<td>365</td>
<td>29.2</td>
<td>260</td>
<td>29.2</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>HV25</td>
<td>Insulate Heating System Components-Building 2371</td>
<td>&lt; 2 yrs</td>
<td></td>
<td></td>
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<tr>
<td>HV26</td>
<td>Provide Temperature Control Of Unit Heaters In Building 2281</td>
<td>0.0</td>
<td>180</td>
<td>11.7</td>
<td>11.7</td>
<td>7</td>
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<td>Total</td>
<td>Kaiserslautern HVAC ECMs</td>
<td>516</td>
<td>41</td>
<td>989</td>
<td>25</td>
<td>67</td>
<td>67 1.3</td>
</tr>
</tbody>
</table>

Note: 1. HV1 Requires moderate investments resulting in up to 20% thermal energy savings with the payback within one heating season
2. This ECM will result in productivity improvement in summer and winter seasons. Requires further study with support from the shop management
3. Implementation of this ECM doesn’t have economical justification but is strongly recommended for safety and health reason
4. Implementation of this ECM doesn’t have economical justification but is strongly recommended for workers comfort reason

4.7 Pirmasens Building Envelope (BE)

4.7.1 BE #16: Install Drop Ceiling in Certain Spaces—Building 4000

4.7.1.1 Existing Conditions

Building 4000 is a tall building with a number of rooms used to perform functions associated with vehicle repair. Some of these areas are served by overhead cranes that need the high space. Other spaces could function well with a much lower ceiling (Figure 11). With a lower ceiling less heat would be needed to maintain room temperatures in the winter. This applies to the wood shop, transmission repair, and an adjacent space to transmission repair. The total area of these spaces is 3,266 sq ft, approximately 2.6 percent of the total building area.

Figure 11. Drop ceiling in Building 4000.
4.7.1.2 Solution

In the spaces that are narrow enough to support a ceiling without interim supports install a new ceiling at a height of approximately 12 ft. This will require a new lighting system, new air diffusers attached to extended ducts tied to the supply and return air systems as well as new ceiling frames and panels. Some of these panels should be transparent to allow light from the skylights above to pass through. The skylights are also operable to allow venting of warm air during the economizer cooling cycle.

4.7.1.3 Savings

It is estimated that dropping the ceiling will save 25 percent of the heat that would be required for these spaces. The total annual heating use for the building is 3,303 MWHth:

\[
Q = 3,303 \text{ MWH} \times 0.026 \times 0.25 = 21.5 \text{ MWHth}
\]

Cost Savings = 21.5 MWHth X $65/MWH = $1,397/yr (1,700 €)

4.7.1.4 Investment

The estimated cost for a new ceiling is $10/sq ft or $32,660 (25,100 €).

4.7.1.5 Payback Calculation

The payback for this project is 23 yrs and thus is not recommended.

4.7.2 BE #17: Close Opening above Crane Using Brushes and Rubber Strips—Building 4000

4.7.2.1 Existing Conditions

In Building 4000 the crane in the middle section of the building can move outside to pick up vehicles or parts that need to be brought inside for repair. When the crane is required to be moved outside, a section of the upper portion of the building is lifted up to allow the crane carriage to pass through the outside wall. Above the two crane rails there are small openings to allow the crane wheels to pass. There is no building component that move into this space to seal these opening so no cold air can enter during the winter.
4.7.2.2  **Solution**

Place rubber flaps or long brush fibers in these spaces to close off the openings.

4.7.2.3  **Savings**

It is estimated that closing these openings will reduce the infiltration by 400 CFM. This will provide an energy savings of 19 MWHth/yr.

\[
Q = 1.08 \times 400 \text{ CFM} \times (64.4 - 39) \text{ °F} \times 6000 \text{ hrs/yr} / 3413 \text{ MWH/Btuh} = 19 \text{ MWHth}
\]

Energy cost savings = 19 MWHth $65/MWHth = $1,254/yr (965 €)

4.7.2.4  **Investment**

The cost to install this rubber flab or brushes is estimated to be $400 each or $1600 (1,230 €) for all four openings.

4.7.2.5  **Payback Calculation**

The resulting payback is 1.3 yrs.

4.7.3  **BE #18: Close Openings in Carpenter Storage Room—Building 4000**

4.7.3.1  **Existing Conditions**

In the storage room above the carpenter shop there are several holes in the outside wall that were required by a previous system that has been removed. These openings allow outside air to enter the building.

4.7.3.2  **Solution**

Place insulated metal panels in these openings that will stop the infiltration of outside air from entering the building.

4.7.3.3  **Savings**

It is estimated that closing these openings will reduce the infiltration by 200 CFM. This will provide an energy savings of 9.6 MWHth/yr. Savings are calculated as:
Energy cost savings = 9.6 MWHth X $65/MWHth = $627/yr (480 €)

4.7.3.4 Investment

The cost to install metal panels to fill these openings is $1,000 (769 €).

4.7.3.5 Payback Calculation

The resulting payback is 1.6 yrs.

4.7.4 BE #19: Add Wall Insulation—Building 4171

4.7.4.1 Existing Conditions

This warehouse building has no insulation in its 25,000 sq ft of wall area. The existing wall is metal siding on the outside with a particle board in the inside. The estimated insulating (U) value of the wall assembly is 0.50 Btu/sq ft/°F.

4.7.4.2 Solution

Provide an insulated wall panel on the outside of the building that is composed of an 1 in. of foam covered by aluminum. The resulting new U-value is 0.09 Btu/SF/°F.

4.7.4.3 Savings

The addition of insulation to the warehouse walls will reduce the annual heating use by:

\[
Q = (0.5 - 0.09) \text{ Btu/sq ft/°F} \times 25,350 \text{ sq ft} \times (64.4 - 39) \text{ °F} \times 6000 \text{ hrs/yr} / 3413000 \text{ Btu/MWH} = 464 \text{ MWHth/yr}
\]

Cost Savings = (464) MWHth X $65/MWH = $30,165/yr (23,200 €)

4.7.4.4 Investment

The estimated cost of installing this new metal panel is approximately $5.00/sq ft of wall area for a total cost of $127,000 (97,700 €).
4.7.4.5  Payback Calculation

The resulting payback is 4.2 yrs.

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings MWh/yr</th>
<th>$K/yr</th>
<th>Thermal Savings MWh/yr</th>
<th>$K/yr</th>
<th>Additional Savings $K/yr</th>
<th>Total Savings $K/yr</th>
<th>Investment $K</th>
<th>Simple Payback yrs</th>
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</thead>
<tbody>
<tr>
<td>BE16</td>
<td>Install Drop Ceiling in Certain Spaces, Building 4000</td>
<td>22</td>
<td>1.4</td>
<td>1.4</td>
<td>32.7</td>
<td>23.4</td>
<td></td>
<td></td>
<td>4.2</td>
</tr>
<tr>
<td>BE17</td>
<td>Close Opening Above Crane Using Brushes and Rubber Strips, Building 4000</td>
<td>19</td>
<td>1.2</td>
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<td>1.6</td>
<td>1.3</td>
<td></td>
<td></td>
<td>4.2</td>
</tr>
<tr>
<td>BE18</td>
<td>Close Openings in Carpenter Storage Room, Building 4000</td>
<td>10</td>
<td>6.6</td>
<td>6.6</td>
<td>1.0</td>
<td>1.6</td>
<td></td>
<td></td>
<td>4.2</td>
</tr>
<tr>
<td>BE19</td>
<td>Add Wall Insulation, Building 4171</td>
<td>464</td>
<td>30.2</td>
<td>30.2</td>
<td>127.0</td>
<td>4.2</td>
<td></td>
<td></td>
<td>4.2</td>
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<td>Total</td>
<td>Pirmasens Building Envelope ECMs</td>
<td>0</td>
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<td>514</td>
<td>33</td>
<td>33</td>
<td>162</td>
<td>4.9</td>
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</tr>
</tbody>
</table>

4.8  Pirmasens CEP

4.8.1  CEP #1: Turn Off District Heating to Buildings In Summer

4.8.1.1  Existing Conditions

The use of district heating in summertime is significant, although there is no real need for heat, unless special circumstances occur (like the cold weather when the energy assessment team visited Kaiserslautern and Pirmasens). During summer periods heat is only needed for heating of tap water. In most cases this is provided by use of electric water heaters. Even so, data sheets show that KAD used 3663 MBTUs of heat in the period June–September during FY 2005, or 1,073 MWh.

4.8.1.2  Solution

Make sure that tap water can be heated by electricity at all facilities. Make necessary investments to ensure that. Shut down all district heating use, close all distribution systems so that no heat is used and is circulating just to create losses.

4.8.1.3  Savings

At an average price of 65 €/MWh the summer heating costs were $70,000 in the summer of FY 2005. Looking at the data sheet it looks like the summer price is 37.3 €/MWh in the summer, which is approximately $47/MWh. The value of the summer saving should be in the area of 95
percent net savings if electric water heaters are used and totally avoiding circulating heat losses. The calculated savings are:

\[
\text{Savings} = 1073 \text{ MWhth} \times 0.95 = 1,019 \text{ MWhth}
\]

\[
\text{Savings} = 1019 \text{ MWhth} \times 47/\text{MWh} = 47,909 \text{ /yr (36,800 €/yr)} \text{ in normal years.}
\]

4.8.1.4 Investment

Provided information indicates that most buildings already have electric water heaters for summer use. Therefore, an additional investment in the area of $20,000 (15,000 €) should be sufficient to achieve the savings.

4.8.1.5 Payback Calculation

The calculated payback will occur within 5 months.

4.8.1.6 Comments

From the data sheets on consumption figures it can be seen that the potential for savings from not using district heating in the summer are much bigger at other places, e.g., Landstuhl Hospital. It is recommended that this issue also be raised at U.S. Army facilities other than KAD.

| Table 11. Pirmasens central energy plant (CEP) ECM summary. |
|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| ECM             | ECM Description | Electrical Savings MWh/yr | $K/yr | Thermal Savings MWh/yr | $K/yr | Additional Savings $K/yr | Total Savings $K/yr | Investment $K | Simple Payback yrs |
| CEP1            | Turn Off District Heating To Buildings In Summer | 1019 | 47.9 | 47.9 | 20.0 | 0.4 |

4.9 Pirmasens Electrical (EL)

4.9.1 EL #2: Switch off Computers When Not In Use—Building 4000

4.9.1.1 Existing Conditions

All computers in the area are on always as IT support suggests to facilitate software updates and back-up runs. Screens are switched off for the night in offices, but in the maintenance areas, the screens are often left on.

In Building 4000 in Pirmasens there are about 40 PCs with flat screen monitors. In other buildings there are obviously some more computers, but these have not been included in the calculation.
4.9.1.2 Solution

Activate power-save features or switch computers off when not in use. The power saving settings will allow to switch off screen or hibernate the hard disk.

Updates and backups can be programmed to take place when the computer is switched on or during the lunch-break.

4.9.1.3 Savings

The saving has been calculated assuming that a computer with 17- or 19-in. monitor is using 150W when the screen is on and that a PC in stand-by mode in night-time with flat screen turned off is using 50W. The weekly power-on time for the computers will be reduced from 168 hrs to 50 hrs. The calculated savings are:

\[
\text{Savings} = 40 \times (168 - 50) \text{ hrs/week} \times 52 \text{ weeks/yr} \times 100\text{W} = 24,544\text{kWh/yr}
\]

\[
\text{Savings} = 24,544\text{kWh/yr} \times 1\text{KW/1,000W} \times 80 \text{ / MWh} = 1,964 \text{ / yr (1,510 €/yr)}
\]

Additional saving may be possible from reduced peak demand if the electricity tariff includes a peak demand cost.

4.9.1.4 Investment

No investment, most computers already have the possibility for power saving. New advice and instructions from IT support are needed.

4.9.1.5 Payback Calculation

There is zero payback time.

### Table 12. Pirmasens electrical ECM.

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings MWh/yr</th>
<th>$K/yr</th>
<th>Thermal Savings MWh/yr</th>
<th>$K/yr</th>
<th>Additional Savings $K/yr</th>
<th>Total Savings $K/yr</th>
<th>Investment $K</th>
<th>Simple Payback yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>EL2</td>
<td>Switch off Computers When Not In Use Building 4000</td>
<td>24.5</td>
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<td>2.0</td>
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</tr>
</tbody>
</table>
4.10 Pirmasens HVAC (HV)

4.10.1 HV #23: Improve HVAC System Controls—Building 4000

4.10.1.1 Existing Conditions

According to Mr. Hans Greb, and also verified by talking to Mr. Weis at the Common Systems section, there are some serious problems with the HVAC system in Building 4000. The building has been in operation since 1990. Insufficient heating and cooling have been experienced since that time. During the team’s initial tour through the building, it was noted that some areas were very hot and other areas cold. The working hours are daytime 5 days/week.

AHUs work with increasing return air volume as it gets colder. Many AHUs have both heating and cooling coils. The AHUs themselves seem to be in good condition, but the controls for the supply air temperatures, room temperatures, regulating valves for heating and cooling as well as circulation pumps for heating and cooling are not coordinated. This results in systems fighting each other and consequent waste of energy.

Setpoints for space temperature varying from 20–50 °C. Large air curtain units do not stop when the big doors have been closed. (The switch at the top of the door has a mechanical problems.) Consequently, temperatures can rise to +35 °C in the main working hall sometimes. The greatest problem, however, is that each circulating pump (of at least 30) for every single secondary heating pipe or cooling pipe has its own timer that controls when the pumps switches on and off. This means that when the AHU in the Common Systems section calls for cooling (when it is too hot in that area), it is not certain that the cooling pump even is running. In fact, it is likely not running since all timers have different settings and may conflict with each other. Many mornings occupants are very cold because the AHU was on all night at maximum cooling.

4.10.1.2 Solution

Start all over again. Invest in a new, centralized HVAC control system, without having to take away all regulators etc. Use as much as possible of the old things (regulators, regulating valves, pumps, temperature sensors etc.) Remove all timers for the heating and cooling pumps. Allow the heat-
ing pumps to run when outdoor temperature is below +15 °C. Allow cooling pumps to run when the outdoor temperature is over +15 °C. Regulate every AHU with respect to exhaust air temperature or space temperature. Use heating and cooling in sequence to prevent simultaneous use of heat and cool.

Run AHUs only during working hours unless they need to be started in some areas for heating purposes, when they should operate with 100 percent return air. Otherwise it is OK with a curve to operate dampers with respect to outdoor temperature. Although it is energy efficient, one should always keep at least 20 percent outdoor air (which should be sufficient with these large AHUs and only 100 people working in the 11,500 m² [133,000 sq ft] building.)

4.10.1.3 Savings

Building 4000 (which is 11,498 m²) uses 3,300 MWh of heat annually, or 287 kWh/m²/yr. This is a large amount for such a new building and with AHUs running on lots of return air. A normal (target) value, is no more than 200 kWh/m²/yr, although the building is quite large:

\[
\text{Savings} = (287-200) \text{ kWh/m}^2 /\text{yr} \times 11,498 \text{ m}^2 \times 1 \text{MWh/1000kWh} = 1,000 \text{ MWhth}
\]

\[
\text{Savings} = 1,000 \text{ MWhth} \times $65/\text{MWhth} = $65,000/\text{yr} (50,154 \text{ €})
\]

There are also substantial savings to be made from less cooling, with functioning controls.

4.10.1.4 Investment

A smart purchaser with assistance from good expertise can keep this investment below $150,000 (115,000 €). In other cases, it can be as costly as someone wants it to be.

4.10.1.5 Payback Calculation

Payback within 3 yrs is very likely, or 3 yrs when considering heating costs only. These changes will result in better productivity and less costs for making calls to the contractor to come and fix the system. (When a contractor is paid for each repair incident, there is less incentive to perform high-quality, lasting work.) Lower costs for cooling will reduce the payback time significantly.
The manager who makes the contract payments should investigate and question the amount the contractor is paid annually for Building 4000.

4.10.2 HV #24: Install Door Heater—Building 4155

4.10.2.1 Existing Conditions

Building 4155 at Pirmasens is used to ship parts for the Depot and it is occupied two shifts/day, 5 days/week. Parts are gathered and taken to this building and assembled in their shipping containers for placement. The entrance door has many fork trucks that pass through it and thus the door is open approximately 25 percent of the time (Figure 12). When open cold outdoor air enters the building creating cold drafts and making the space uncomfortable.

Figure 12. Door in Building 4155.

4.10.2.2 Solution

Place a door heater at this door to reduce the outside air that enters the building. This door heater will also temper the air that does enter the building through the door.

4.10.2.3 Savings

The addition of a door heater on this door will reduce the amount of cold air entering the building. There will be an estimated 3,000 CFM reduction
in the infiltration of outside air that would require heating. Savings are calculated as:

\[
Q = 1.08 \times 3,000 \text{ CFM} \times 25\% \times (64.4 - 39) ^\circ F \times 2080 \text{ hrs/yr} / 3413 \text{ MWH/Btuh} = 13 \text{ MWHth}
\]

Energy cost savings = 13 MWHth $65/MWHth = $815/yr (630 €)

4.10.2.4  Investment

The approximate cost for a 12,000 CFM heater for this 10 ft x 12-ft door is $25,000 (19,200 €).

4.10.2.5  Payback Calculation

The resulting payback is 30.6 yrs.

4.10.3 HV #25: Improve H&V System Controls and Air Movement—Building 4171

4.10.3.1  Existing Conditions

Building 4171 in Pirmasens is essentially a warehouse for medicines. The building is occupied weekdays between 6.30 and 19.30. In parts A and B of the building (the oldest parts), heat is provided by oil-fired infrared heaters. These are controlled from a central panel, which has switches Off / Auto / Day / Night. However, the clock identifies “day” or “night” operations (and thus change temperature setpoints) is not working.

Thermostats for the IR-heaters are placed between shelves for automatic trucks. Researchers noted that a thermostat in one of the bays was set at 43 °C, probably changed from the normal 20–22 °C by someone who felt cold one day. According to Karl-Heinz Gaa, who works for the contractor Wisag, the normal setpoint (depending on the products) is 20–22 °C during the day, and +15 °C at night. The question remains whether the products would accept lower temperature at night.

In part C (a newer part), the heat is provided via heated air from two direct oil-fired Robatherm AHUs, at 30,000 m³/h each. These normally run at a minimum outdoor air flow of 20 percent. They can never be stopped, due to safety reasons with the direct firing of oil into the unit. Supply air
temperature was +60 °C during the site visit to the building. It is doubtful that existing diffusers can direct the heat down to the floor.

4.10.3.2 Solution

Parts A and B: As at other locations: thermostats should be placed in locked cages, and operated only by the supervisor, who will have the only key. Make necessary investments in programmable timers so the temperature can be reduced to +15 °C at night.

Part C: Replace existing controls of the AHUs with new and modern regulators and controls that can allow the units to stop when nobody works. Control supply air temperature with a maximum of +35 °C and a minimum of +15 °C, depending on measured exhaust air temperature. If a running time of 10 minutes after the burner stops is programmed and if the burner is not allowed to start until the fan is running, the safety issue should be resolved. Allow 15 °C at night as the space temperature (i.e., the exhaust air temperature). It might also be that the burners are too big today, making it necessary to replace existing burners with new, easier to regulate, smaller burners. Perform smoke tests to evaluate the efficiency of air diffusers, which might work better with lower supply air temperature. If they do not, consider changing air diffusers so that the heat can reach the occupancy zone.

4.10.3.3 Savings

Part A and B
At this stage, not enough is known about how the thermostat setpoints have been manipulated and when to make any calculation on the savings. However, upgrading the controls, allowing night-time setback of indoor temperature, will save at least 20 percent of the oil used for the radiant heaters in parts A and B. Unfortunately those specific numbers were unavailable, but a qualified guess, based on an estimated floor space of 9,500 m² for parts A and B together, indicates that the 20 percent corresponds to approximately 50 m³ of oil worth around $26,000/yr. (Data sheets indicate that Building 4171 used 41.3 m³ of oil in March 2006, which translates to an annual energy use of over 300 m³/yr. Twenty percent of 300 m³ is more than what is assumed above.)
Part C

Stopping AHUs 10 hrs/weekday and both Saturday and Sunday will save 105 MWh of electricity (from not running the fan motors) worth $6,300/yr. Changing control method to exhaust air temperature control will prevent overheating and thus unnecessary losses through the roof and doors. Reducing the supply air temperature and allowing lower night and weekend temperatures will save at least as much as for electricity, making the total savings sum up to 105 MWh electricity and 100 MWh of oil (10 m³) worth totally $13,500/yr (10,400 €/yr).

4.10.3.4 Investment

The total investment for Building 4171 should not exceed $20,000 (15,000 €).

4.10.3.5 Payback Calculation

Total payback time for investments in Building 4171 is less than 6 months.

4.10.4 HV #26: Install Economizers—Building 4111

4.10.4.1 Existing Conditions

At present, the boiler plant generates hot water at a maximum temperature of +110 °C (see HV #32). To accomplish this, the boilers generate 3.3 bar steam at +150 °C. The flue gases from the boilers are normally at +170–180 °C. This is quite high due to the 110 °C hot water distribution temperature. Capacity of boiler is 8,000 kg/h of 8 bar steam.

4.10.4.2 Solution

When the hot water temperature is reduced (as suggested below), install an economizer that can reduce the flue gas temperature to a maximum of 120 °C. This will take more energy out of the used fuel.

4.10.4.3 Savings

Can be calculated as follows:

- Flue gas flow: m³/s.
- Reduced flue gas temperature: 50 °C
- Fuel costs: $50/MWh
Cp air at 120 °C: 1.015 KJ/kg °C
Density air at 120 °C: 0.9 kg/m³
Boilers operated Oct 1 to May 31 = 243 days = 5832 hrs/yr
Per Boiler Savings: m³/s * 1.015 KJ/kg °C * 0.9 kg/m³ * $50/MWh * 5832 hr/yr *
3,600s/hr x 50 °C x 1MWh/3,600,000KJ = $13,320 * x, i.e., for every m³/s
of flue gases, the annual savings of reducing the flue gas temperature is
$13,320 (10,200 €/yr) per boiler, or for all three boilers a savings of
$39,960/yr.

4.10.4.4 Investment

The estimated cost to install an economizer in one of these boilers is
$30,000, for a total cost of $90,000 (69,000 €).

4.10.4.5 Payback Calculation

The payback on this project is 2.3 yrs:

Payback = $90,000/$39,960/yr = 2.3 yrs

4.10.5 HV #27: Reduce Hot Water Temperatures—Building 4111

4.10.5.1 Existing Conditions

The distribution of hot water from the boiler plant in Building 4111 to the
various buildings in Pirmasens follows a curve: At a temperature of –10 °C
or colder outdoors, the hot water temperature is 110 °C. At +10 °C or
warmer (until the boiler plant is shut down, normally on 31 May) the hot
water temperature is 85 °C. A linear curve between these points indicates a
supply temperature between +10 and – 10. The spontaneous impression is
that this is much too high, at both ends of the curve. This is based on the
fact that the ΔT, i.e., difference between supply and return temperatures,
 normally is only 15–20 °C. At very cold winter days, it can reach 30 °C.
With such low ΔT, the energy used to pump water around the system is
very high compared to normal district heating systems.

4.10.5.2 Solution

Try to change present heating curve so that the maximum can be lower
than 110 °C and also so that the minimum temperature can be much lower
than 85 °C. (It cannot be necessary to pump around 85 °C water in the sys-
tem when it is warmer than +10 °C. A suggested minimum would be +40 °C at +10 °C, and a suggested maximum would be +90 °C at –15 °C, with a linear curve in-between.

It is also suggested that the hot water flow be reduced, although only in cooperation with the people that are in charge of AHUs, radiators etc. This will likely lead to some replacement of inefficient regulating valves and thermostats etc. so that the change does not take the heat out of the system, but lets water just circulate, more or less.

4.10.5.3 Savings

Savings come from reduced losses in the system. When it is warmer than +10 °C, most of the energy used simply keeps the distribution network hot. If the water flow is reduced, energy savings will accrue from less pumping. However, at this stage, it is not possible to estimate the savings.

4.10.5.4 Investment

No investment will be required to change the curve.

4.10.5.5 Payback Calculation

The calculated payback will occur immediately.

4.10.6 HV #28: Install Measurement Equipment—Building 4111

4.10.6.1 Existing Conditions

Building 4111 is the boiler plant, with three boilers that operate on gas or oil. (Last winter, according to Mr. Weber, the plant ran on 60 percent gas and 40 percent oil.) The boiler controls are not optimal. The people working there have no control of the actual boiler efficiency, making it difficult to optimize boiler operation.

4.10.6.2 Solution

Keep track of boiler efficiency (by installing measuring equipment) to always be able to supervise and optimize boiler operation. Alarms should function so that, when efficiency drops, an active personnel or the operator on duty is alerted.
4.10.6.3 Savings

Savings will result from better boiler performance. In FY05, the use of gas and oil at Pirmasens was 55481 MBTU (gas + oil), or 16,250 MWh. That probably also includes Building 4171. (However, assume that all this energy was used to produce district heat at Building 4111.) A 2 percent increase of the efficiency of the boilers would reduce the purchase of gas and oil by 325 MWh, worth $16,500/yr. A 5 percent efficiency increase would save over $40,000/yr (31,000 €/yr).

4.10.6.4 Investment

Installing sensors to measure the critical parameters of the boilers and with an active program at a computer to show actual data as well as historical data should not cost more than $50,000 (38,000 €) for all three boilers together.

4.10.6.5 Payback Calculation

Depending on the present efficiency and how much the efficiency can be improved, payback is estimated to occur in 1–3 yrs.

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings MWh/yr</th>
<th>Thermal Savings MWh/yr</th>
<th>Additional Savings $/yr</th>
<th>Total Savings $/yr</th>
<th>Investment $K</th>
<th>Simple Payback yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV27</td>
<td>Improve HVAC System Controls Building 4000</td>
<td>0.0</td>
<td>1000</td>
<td>65.0</td>
<td>65.0</td>
<td>150</td>
<td>2.3</td>
</tr>
<tr>
<td>HV28</td>
<td>Install Door Heater, Building 4155</td>
<td>13</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>25.0</td>
<td>29.6</td>
</tr>
<tr>
<td>HV29</td>
<td>Improve H&amp;V System Controls and Air Movement In Building 4171, Pir- masens</td>
<td>105</td>
<td>8.4</td>
<td>26</td>
<td>34.4</td>
<td>20</td>
<td>0.6</td>
</tr>
<tr>
<td>HV30</td>
<td>Install Economizers, Building 4111, Pirmasens</td>
<td>0.0</td>
<td>799.2</td>
<td>40.0</td>
<td>40.0</td>
<td>90</td>
<td>2.3</td>
</tr>
<tr>
<td>HV31</td>
<td>Reduce Hot Water Temperatures—Building 4111 Pirmasens</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Immediate</td>
</tr>
<tr>
<td>HV32</td>
<td>Install Measurement Equipment, Building 4111</td>
<td>16.5</td>
<td>1.3</td>
<td>812.5</td>
<td>41.9</td>
<td>50</td>
<td>1.2</td>
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<tr>
<td>Total Pirmasens HVAC ECMs</td>
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<td>10</td>
<td>2,625</td>
<td>172</td>
<td>0</td>
<td>182</td>
<td>335</td>
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</tbody>
</table>

Note: 1. This no-cost ECM will reduced heat losses in the system with an immediate pay-back
5 Ansbach, Katterbach Kaserne and Storck Barracks in Illesheim

5.1 Ansbach, Illesheim, and Katterbach ECM Analysis

5.1.1 HV #29: Commissary at Katterbach Building 5805

5.1.1.1 General Site Information

- The building is an old hangar, which has been retrofitted and serves as a commissary in one part of the building and a gym in the other. Gross area 52,330 sq ft (4,868 m²), Net area 46,050 sq ft (4,283 m²)
- Retail part has a warehouse with three storages, one of them is cool storage (2 cooling units) and one is cold storage with freezers (5 units).
- The building is connected to district heating system and an electrical grid.
- Operation: 06:00 01:30.
- Open to public between 10:00 and 18:00 5 days a week, between 10:00 and 19:00 1 day a week. Closed on Mondays.

Required temperature in facility: 68 – 72 °F

5.1.1.2 Contact Persons

- Store director: Patrick Hutchins
- Regina Krantz – energy engineer
- Dieter Gerber – electrical engineer
- Helmut Wieder – Technician (UEMCS)

5.1.1.3 Energy Consumption

- Heating energy for year 2005 was 400 MWh
- Electric energy for year 2005 was 1,009 MWh
- The consumption is for a whole building with combined operations.
- Energy bill for year 2005 was 77,911 €.
- Heating: 17,027 €
- Electricity: 60,884 €
- Price of heating energy was 65.76 €/MWh (including fixed prices).
- Price of electricity was 59.46 €/MWh (including fixed prices).
5.1.1.4 Ventilation

The retail shop was equipped with mechanical ventilation system. The system is located in the open attic. Air diffusers are connected using flexible ducts. Air supply is located in the central part of the retails area, and exhaust is from the sides of the retail area. The attic performs as an exhaust chamber. One reason for that is the bearing capacity of the hanging ceiling to hold additional weight.

The warehouse has air handling units providing heating and cooling. Roof has a poor insulation which results in higher heating and cooling loads on the HVAC systems.

Based on the light smell in retail area, it may be suggested that the retail area is under negative pressure against the warehouse which results in the airflow flow from warehouse.

5.1.1.5 Heating

The performance of the radiators in the offices should be checked and avoid the heating by ventilation (if the possibility exists)
There were circulation devices over the retail shop doors, which, according to the manager, did not work properly. This condition could be improved by changing the construction. Also the efficiency should be checked.

5.1.1.6 Existing Conditions and issues

The Commissary (Figure 14) has a number of problematic areas that can be improved:

- The cashier area is cold and drafty.
- The air curtain system is under dimensioned.
- The air recirculation rate (80 percent) is too high.
- Warm air is collected between ceiling and roof.

5.1.1.7 Solution

- Reduce the air rate by reducing fan speed in the summer time but the outside air rate has to remain constant,
- Integrate the air curtain system in the controls.
- Lengthen the air lock to avoid both doors open at the same time.
- Supply the air lock with exhaust air for heating and pressure maintenance.
- Exhaust air through the insulated duct.
- Install ceiling insulation.
• Install additional fan for exhaust air with the same airflow rate as for supply air fan) and transport this air to the air lock. Install an over-pressure controlled outlet between air lock area and outside.

5.1.1.8 Savings

Old insulation: \( u = 2 \text{ W/m}^2\text{K} \)
New insulation: \( u = 0.5 \text{ W/m}^2\text{K} \)
Area: 1,100 m²
Mean outside temperature: 4 °C
Use: 8 h/d ; 6 d/w ; 250 d/yr (= 1,715 h/yr)
Energy costs: $65/MWh
Loss through air curtain: $750/yr
Energy loss with old insulation: \( 2 \text{ W/m}^2\text{K} \times 1,100 \text{ m}^2 \times (20-4) \text{ K} \times 1,715 \text{ h/yr} = 60.4 \text{ MWh/yr} \)
Energy loss with new insulation: \( 0.5 \text{ W/m}^2\text{K} \times 1,100 \text{ m}^2 \times (20-4) \text{ K} \times 1,715 \text{ h/yr} = 15.1 \text{ MWh/yr} \)
Saving: \( (60.4 - 15.1) \text{ MWh/yr} \times $65/\text{MWh} + $750/\text{yr}= $3,695/\text{yr} \)

5.1.1.9 Investment

Cost of insulation: \$20/\text{m}^2 \times 1,100 \text{ m}^2 = \$22,000

5.1.1.10 Payback Calculation

Payback: \$22,000/ \$3,695/\text{yr} = 5.9 \text{ yrs}

5.1.2 HV #30: Energy Retrofit in Gym, at Katterbach Building #5805

5.1.2.1 Problem

This building is very hot in summer and the systems are very noisy. There is no control connection between the supply and exhaust systems, and no heat recovery from exhaust air. Systems are allowed to run even when no one is inside.

5.1.2.2 Solutions

Install external shading in front of the windows. Install control connection between supply and exhaust systems. Demand control ventilation with CO2 sensors. Perform heat recovery in winter time
5.1.2.3  Payback Calculation

Short pay-back period.

5.1.3  HVs #31, #32, #33, #34, #35, #36, #37, #38: Replace Warm Air Heating System with a Hot Water Radiant Panels in Hangars, Katterbach and Ilesheim

5.1.3.1  Existing Conditions

A typical layout for hangars is a total area of 3000 to 5000 m², of which 1000 m² to 1500 m² is for aircraft service and the rest is smaller workshop and office spaces. The typical dimensions of the aircraft service area are:

- width and length 30 – 50 m
- depth 15 – 30 m
- height 10 – 15 m.

The heating of the building is water based system; radiators in the workshops and offices, air heaters in the aircraft service areas. The air heaters circulate the air and heat it to a temperature levels of 25–45 °C depending on the heat demand.

The hangars are occupied according to the flight schedules and that means that occupation of the building significantly varies. The most challenging situation for thermal comfort in the hangar is during the winter time when a new aircraft is being moved into the building. The large doors, size of 20x10 m can be open for several minutes and the air of the hangar will be changed several times during the doors being open. The aircraft that will be moved in can weight several tons and has a body with 0 °C temperature.

5.1.3.2  Problems

Warm air heating units and systems installed in the upper zone of hangars do not satisfy thermal comfort requirements in the occupied zone.

Besides, warm air heating is inefficient when air is supplied in high bays with a low speed. When the helicopter is brought in the building in winter time, technicians have to wait a few days before they can start to repair it because the helicopter is too cold, which has an impact on the mission.
The building heating systems are not dimensioned to heat the aircraft during a short period of time. The necessary heat capacity for the warm up of the helicopters has to come from an additional special / separate heating system.

![Figure 15. Typical warm air heating units used in hangars.](image)

**5.1.3.3 Solution**

The circulating air heaters (Figure 15) shall be replaced with radiant heating panels installed at the ceiling level. The panels can use the same hot water system that is used by warm air circulation units.

Building # 5807, Katterbach is used as an example to estimate energy and cost savings. Calculations for other hangars are similar.

Area: 1,930 m²
Energy used for building heating:
1191 MWh - 50% of the total hangar heating energy.
Energy savings per year: 25%
Energy costs: $60/MWh
Saving: 50% * 1,191MWh * 25% * $60/MWh = $8,940 /yr
Installation of heat radiator panels:
Panels 90 pieces (3m length) * $525/panel = $47,250
Piping 100 m * $62.5/m = $6,250
Design $1,250/d * 5d = $6,250
Total cost: $59,750
Payback: $59,750 / $8,940/yr = 6.68 yrs

Table 5 lists calculated cost and savings for hanger circulating heaters based on the fact that the efficiency of the radiant heating is about 25 percent better than that of a corresponding circulating air system.

Table 14. Summary of cost and savings for hanger heating system retrofits.

<table>
<thead>
<tr>
<th>ECM</th>
<th>Building</th>
<th>Ceiling Area (m²)</th>
<th>Heating Demand (kW)</th>
<th>Demand per Unit Area (W/m²)</th>
<th>Unit Size (W)</th>
<th># Units</th>
<th>Total Cost ($)</th>
<th>Energy Savings (MWh/yr)</th>
<th>Savings ($)</th>
<th>Payback (yrs)</th>
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</thead>
<tbody>
<tr>
<td>HV35</td>
<td>Katterbach 5807</td>
<td>1930</td>
<td>158</td>
<td>79</td>
<td>1750</td>
<td>90</td>
<td>59750</td>
<td>149</td>
<td>8940</td>
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<td>HV36</td>
<td>Katterbach 5801</td>
<td>1550</td>
<td>122</td>
<td>78</td>
<td>1750</td>
<td>71</td>
<td>40000</td>
<td>90</td>
<td>5900</td>
<td>6.7</td>
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<tr>
<td>HV37</td>
<td>Katterbach 5802</td>
<td>1600</td>
<td>125</td>
<td>78</td>
<td>1750</td>
<td>71</td>
<td>40000</td>
<td>100</td>
<td>6000</td>
<td>6.7</td>
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<tr>
<td>HV38</td>
<td>Katterbach 5508</td>
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<td>167</td>
<td>76</td>
<td>1750</td>
<td>95</td>
<td>50000</td>
<td>107</td>
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<td>Katterbach 5806</td>
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<td>215</td>
<td>76</td>
<td>1750</td>
<td>123</td>
<td>62000</td>
<td>80</td>
<td>4800</td>
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<td>HV40</td>
<td>Illesheim 6500</td>
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<td>288</td>
<td>74</td>
<td>1750</td>
<td>165</td>
<td>79000</td>
<td>269</td>
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</tr>
<tr>
<td>HV41</td>
<td>Illesheim 6501</td>
<td>1932</td>
<td>147</td>
<td>76</td>
<td>1750</td>
<td>84</td>
<td>45000</td>
<td>142</td>
<td>8520</td>
<td>5.3</td>
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<tr>
<td>HV42</td>
<td>Illesheim 6502</td>
<td>3860</td>
<td>283</td>
<td>73</td>
<td>1750</td>
<td>162</td>
<td>83000</td>
<td>235</td>
<td>14100</td>
<td>5.9</td>
</tr>
</tbody>
</table>

*Energy cost: $60 /MWh

5.1.4 HV #39: Flight Simulator, Building # 6658, Illesheim

Figure 16 shows Building # 6658, Illesheim, which houses the flight simulator.

Figure 16. Flight simulator, Building 6658, Illesheim.
5.1.4.1  General Information

Date built: 1983
Gross area: 35,753 sq ft (3,321 m²)
Net area: 26,715 sq ft (2,482 m²)
The building consists of three sections, A, B and C.
Section A was not in use.
In section B, there are office spaces, storages, classrooms, one simulator room and
a computer room.
Section C is a simulator hall and some offices related to the simulator operation.
The building is connected to district heating system and electrical grid.
Running hours
Black Hawk UH-60
Government 08:00 – 20:00 daily
Contractors: 06:00 – 23:00 daily
Two simulators: AH-64D
Government: 12 hrs / day
Contractors: 05:00-19:00
Indoor air requirements
  Required temperature in facility: 15.5 °C – 26.6 °C
  Offices 20 – 22 °C, Rh 40 – 60 percent
  Computer room and flight simulator 18.3 – 23.3 °C, Rh = 45 – 65 percent
Contact Persons:
  Ron Boese, Quality Assurance Engineer
  Kenneth Halter, Manager
  Regina Krantz, Energy Engineer
  Dieter Gerber, Electrical Engineer
  Helmut Wieder, Technician (UEMCS)

5.1.4.2  Energy Consumption

Heating energy for year 2005 was 896 MWh (270 kWh/m²).
Electric energy for year 2005 was 2 316 MWh (697 kWh/m²).
Energy bill for year 2005 was 196 629 €.
Heating: 58 923 €
Electricity: 137 706 €
Price of heating energy was 65.76 €/MWh (including fixed prices).
Price of electricity was 59.46 €/MWh (including fixed prices).
Heating energy consists of losses through the building envelope, heating of supply
air and heating of domestic water (see Figures 17 and 18).
Electrical energy is used mostly for running the flight simulators and maintaining the indoor air conditions.

Figure 17. Building 6658 heating energy breakdown.

Figure 18. Building 6658 electrical energy breakdown.
5.1.4.3 Systems

5.1.4.4 Building Envelope

Exterior Walls

1. Light concrete block (approximately 20 cm, insulation in between) + metal sheet cover with insulation; estimated U-value 0.30 W/m²,K
2. Steel structures with metal sheet cover with insulation. Insulation approximately 10 cm, estimated U-value 0.45 W/m²,K
3. Roof: Concrete slab with insulation (15 cm), estimated U-value 0.30 W/m²,K

Windows

Thermal panes with light metal frames, U-value is most probably >2.0 W/m²,K. There is a condensation duct in the frames, i.e., direct connection outside, which decreases the total U-value of the window

Window area is relatively small compared with the rest of the building envelope. Some tracks of possible moisture in the windows.

Windows and doors need maintenance, almost all the doors have direct air flow route to outdoor. Seams leak.

Doors

1. Metal doors with insulation
2. Double light metal doors with panes (main entrance)

Based on visual inspection, there were no visual damages in the foundations. Walls all over covered with metal sheets were in acceptable condition, no visual findings from the roof.

5.1.4.5 AC System

The indoor air temperature and humidity are maintained with four AC units.

1. Offices
2. For FS trailer
3. Not in use
The units are equipped with heating, cooling, humidification and return air function (see Figure 19). AC units are run using constant air volume and 24/7.

Inefficiencies: Inefficient humidification and dehumidification strategies of AC units.

Wastes: AHU of office space is run 24/7.

5.1.4.6 Electrical

Electrical supply is connected to transform station. There were two 1000 kVA transformers in use and one 1000 kVA transformer not in use.

5.1.4.7 Indoor Air Quality

All the office rooms on the left side of the lobby were cold and drafty and according to the users very cold in the winter. Additional electric heaters were in use. Also the office room (not originally designed for that purpose) by the trailers were cold. (Extra heaters were in use.) Relative humidity has been relatively high according to the users.
5.1.4.8 Problems

- High energy consumption by HVAC systems.
- Constant volume systems for both high bay areas with simulators at a variable load.
- Mixing losses in the AHU (air treatment).
- Inefficient fans and motors.
- Old chillers.
- Control system is out of order. Inefficient pneumatic controls. Sensors not calibrated. No hydraulic adjustment.
- HVAC running time doesn’t correspond with simulators use. Air rate cannot be changed with the load. No heat recovery system.

5.1.4.9 Recommendations

Replace pneumatic controls with DDC controls. Airflow control needs installation of frequency converter.

Additional insulation is probably not cost effective. However, air leaks through the windows and doors shall be as a part of the normal maintenance work.

Needs further evaluation of required airflow rate, heating and cooling loads, requirements to air quality, process and comfort related thermal requirements in the various parts of the building should be evaluated. The real cooling need of the building and simulators should be evaluated with logger measurements. Chillers and their operation and running order should be inspected too. After that it is recommended to:

- separate HVAC service areas from each other
- commission HVAC systems to operate in required levels
- install frequency converters and controls for to operate fans
- potential for speed controlled pumps.

Replace old equipment with the new, since it is way over its operational lifetime.

Based on the above analysis, this building has significant potential for energy savings and improvement in thermal comfort and indoor air quality. However, based on importance of the mission and complexity of process
and building systems, a Level II energy audit is required to analyze specific energy conservation measures and resulting savings. This assessment should be performed in cooperation with consultants and the users and maintenance personnel of the facility.

5.1.5 LI #19: Improve Lighting Efficiency in Hangars

5.1.5.1 Issue

Inefficient lighting due to dark floors and inefficient lighting systems resulting in increased electrical energy consumption.

5.1.5.2 Solution

Consider holistic lighting solution which includes reducing the number of lamps, changing the lamps to more energy effective and improve the illumination by treating the floor surfaces to be more reflective as in the Hangar 2, Katterbach.
Table 15. Ansbach, Illesheim, and Katterbach recommended ECMs.

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings MWh yr</th>
<th>$K/yr</th>
<th>Thermal Savings MWh yr</th>
<th>$K/yr</th>
<th>Additional Savings $K/yr</th>
<th>Total Savings $K/yr</th>
<th>Investment $K</th>
<th>Simple Payback yrs</th>
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<tbody>
<tr>
<td>HV33</td>
<td>Heating system improvement in Commissary at Katterbach Building 5805</td>
<td></td>
<td></td>
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<td>HV34</td>
<td>Energy Retrofit in Gym-Building 5805</td>
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<tr>
<td>HV35</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5801</td>
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<td>LI19#</td>
<td>Improve Lighting Efficiency in Hangars</td>
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<td></td>
<td></td>
<td>6.45</td>
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</table>

Note: 1. Complex implementation of this ECM will reduce energy consumption and will result in improved thermal comfort, Short payback period.
2. This building has a significant potential for energy savings and improvement in thermal comfort and indoor air quality. Requires a Level II energy audit.
3. This ECM provides a holistic approach to lighting solution which includes reducing the number of lamps, changing the lamps to more energy effective and improve the illumination by treating the floor surfaces to be more reflective as in the Hangar 2, Katterbach. Payback in 2-3 yrs.
6  **Annex 36 Energy Concept Adviser (ECA) Application at Two U.S. Schools in Wiesbaden, Germany**

Prepared by Heike Erhorn-Kluttig, Hans Erhorn, Anna Staudt (Fraunhofer-IBP)

Energy Concept Adviser (ECA) developed under the International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems (ECBCS) Annex 36 was used to assess potentially energy savings at two schools located at the U.S. Army Garrison Wiesbaden. This study was conducted by Heike Erhorn-Kluttig, Hans Erhorn and Anna Staudt (Fraunhofer Institute of Building Physics, Stuttgart) in August 2006.

### 6.1 Summary

The ECA tool should be tested on a U.S. school in Germany. The U.S. Army Corps of Engineers, through their contacts in Germany, chose two schools, the Elementary and the Middle School Hainerberg in Wiesbaden Hainerberg. A building visit took place on 18 August 2006. Both schools were visited in a common inspection activity by one representative from the Engineer Corps of the U.S. installation (Mr. Utermöhlen), partly assisted by the facility manager, and by three researchers from Fraunhofer-IBP for altogether about 5 hrs. During this visit the team made a thorough analysis of the existing state of the building including the building components (non-destructive analysis, only), the service systems and investigations at the users (school principals and caretakers). Before the visit electronic architectural drawings were sent and during the visit additional plans were handed. However it has to be mentioned that the drawings were only floor plans of differing quality, no sections were available. The following report summarizes the found existing state of the two buildings and the input into the tool and the results of the calculation made with the ECA tool. All areas, volumes, and the input of both schools were calculated in 10 hrs, and the report was constructed in 2 hrs. During the visit it became clear that the chosen examples were not the most suitable for the ECA test as the schools were both in very good shape and some retrofit measures had already been realized.
For the use of the ECA, the parts of the buildings that cannot be included are: the sports hall, the assembly hall (used as canteen, too), and the school kitchen. Table 16 and Figures 20 and 21 describe and show the school buildings.

### Table 16. General Data

<table>
<thead>
<tr>
<th></th>
<th>Elementary School</th>
<th>Middle School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address of project</td>
<td>Hainerberg Elementary School Building 07778 Texasstraße 65189 Wiesbaden</td>
<td>Hainerberg Middle School Building 07778 Texasstraße 65189 Wiesbaden</td>
</tr>
<tr>
<td>Year of construction</td>
<td>1982</td>
<td>1954</td>
</tr>
<tr>
<td>Year of renovation</td>
<td>- probably 1982 (now same windows as Elementary School)</td>
<td>- roof insulation</td>
</tr>
<tr>
<td>Renovations</td>
<td></td>
<td>- connection to district heating system (original plan: coal cellar)</td>
</tr>
<tr>
<td>Total floor area</td>
<td>12264 m²</td>
<td>6862 m²</td>
</tr>
<tr>
<td>Number of pupils</td>
<td>~ 810 pupils</td>
<td>~ 420 pupils</td>
</tr>
<tr>
<td>Number of class rooms</td>
<td>53</td>
<td>34</td>
</tr>
<tr>
<td>Typical classroom</td>
<td>115 m²</td>
<td>94,5 m²</td>
</tr>
</tbody>
</table>

Figure 20. Hainerberg Elementary School.
6.2 Site

Wiesbaden, which is located near the center of the Hainerberg area, is surrounded by U.S. military barracks and other military buildings, and has the following geographic characteristics:

- Latitude: 50.3
- Longitude: 82
- Altitude: 120 m above sea level
- Test reference year: TRY Frankfurt.

6.3 Typology/Age

The two blocks now used as the Middle School were built in 1954. In 1982, the other school part (used as Elementary School) was added with a facade view similar to that of other older school buildings. A small part of the Elementary School is used as kindergarten, which also has an additional separate building.

6.4 Building Construction

The two buildings are attached to each other. Figures 22–24 show general and detailed floor plans for the Elementary School and Middle Schools.
Figure 22. General floor plan layout of the Elementary (left) and Middle (right) Schools.

Figure 23. Elementary school floor plan, Building 7778, first floor.
6.4.1 Elementary School

The exterior wall (Figure 25) consists of reinforced concrete panels between reinforced concrete columns. The concrete panels are covered from the outside with about 4 cm of mineral wool, 2 cm ventilated air gap and either additional 12 cm concrete panels, or concrete panels with glued clinker (2 cm) between the windows.

The red aluminum-framed windows (Figure 26) are double glazed, filled with air. Every second window is operable. The frames do not include a thermal barrier. All windows are covered with a foil (profilon) fixed on the
internal side that prevents splitting and works as a shade. The foil was recently added and seems to be a requirement for all U.S. military school buildings.

Figure 26. Double glazed red aluminum-framed windows.

The classrooms, traffic areas, and other room types have suspended acoustical ceilings that include the lighting systems (Figure 27). The floor construction contains partly cable ducts. The unobstructed room height is 2.75 m. A special case for the classroom situation is on the second floor where above the library (media centre) area, four sets of four classrooms are grouped around a common room in the centre area.

Figure 27. Typical classrooms with suspended acoustical ceilings that include lighting systems.

The Elementary school has a flat roof (Figure 28) that was renovated in 2002. It consists of steel, insulation, sealing, and grit as cover. The building has a small partial basement. In most areas, it has a base slab. Neither
the cellar ceiling nor the base slab is insulated, both are constructed with reinforced concrete.

6.4.2 Middle School

The Middle School is as explained the older building, the newer Elementary School was adapted in its façade outlook to the Middle School. The exterior walls are also constructed with reinforced concrete columns. The fields between the columns consist of concrete panels with fixed clinker without insulation and air gap (Figure 29).

The windows have been exchanged in an earlier retrofit and are similar to those of the Elementary School. The aluminum-framed windows in red have a double pane glazing, filled with air. The frames are again without thermal barrier. All windows are covered with a foil (proflon) that prevents splitting and additionally works as a shade. The foil was added not so long ago and seems to be a requirement for all U.S. military school buildings. Here the shading system is on the external side. The classrooms and the traffic areas show suspended acoustic ceilings (Figure 30).
The second floor has an inclined roof (Figure 31). Originally the corridor in the middle of two classroom wings had a skylight that provided additional daylight to the classrooms. For fire safety, these skylights were removed from the classrooms and the corridor, which were then painted and glazed white, and insulation was added to the exterior part of the roof, including the formerly exterior glazing. The fire safety (F90) was achieved by adding gypsum boards to the interior glazing and the corridor ceiling.

About half of the building has a basement. The basement rooms are on the one side used as additional classrooms if necessary and on the other side as storage rooms. The storage rooms have a lower ceiling height. There is no insulation on the cellar ceiling nor on the base slab, both are made of concrete. Under the other part of the building, there is a crawl space.
6.5 Heating/Ventilation/Cooling and Lighting System

6.5.1 Heating System

Both buildings use district heating as generation system. The supply heating water is provided via a heat exchanger (Figure 32).

![Figure 32. Heat exchanger.](image)

The distribution system is either in the crawl cellar of the Middle School (Figure 33) or above the suspended ceilings in the Elementary School. The pipes are insulated.

![Figure 33. Middle School crawl cellar.](image)

The Elementary School uses convectors (e.g., library, kindergarten) or radiators (classrooms) as emission system, the Middle School radiators. It has to be mentioned that in part of the Elementary School, specifically the kindergarten, cupboards are placed in front of the convectors, which prevents effective and quick heating of the rooms.
6.5.2 Domestic Hot Water System

The Elementary school offers hot water in all classrooms. Partly this is realized centrally, partly decentralized by small electric hot water boilers. The lavatories in both schools offer mostly central hot water. The DHW storage heated by the district heating contains 145 L for the Elementary School.

6.5.3 Ventilation

Ventilation is mostly realized naturally by operable windows. For some special classrooms like the 4X4 grouped classrooms in the Elementary School and chemical and cookery classes in the Middle School, additional mechanically exhaust ventilation is provided.

The canteen in the multi-purpose room of the Elementary School features an air-heating system. The fresh air rate can be manually adjusted. The heat register is directly connected to the district heating system. There is no heat recovery. The ventilation system is from the time of the construction of the building. In the lavatories, exhaust ventilation systems have been added within the windows. In some server rooms, an exhaust ventilation system has been installed.

6.5.4 Cooling

Very few special rooms have a cooling system with a split unit of 12.5 kW.
6.5.5 Lighting

All classrooms have daylighting access from one of the exterior walls. Most classrooms have a renewed artificial lighting system with electronic ballasts and fluorescent tubes with either 18 W per tube or 36 W per tube direct lighting. A typical classroom has eight luminaires with four 36W tubes for an area of 115 m² (Figure 35).

The luminaires in the classrooms are manually controlled in two segments (façade near, middle, and corridor near). Additionally the middle and corridor near area can be reduced by 50 percent of the tubes. Alternatively, two other control strategies mainly in the Middle School have been detected:

- All luminaires can be reduced by 50 percent of the tubes. No distinction between façade near area and corridor near area
- Some classrooms have a control that can turn off parts of the luminaires, but unfortunately divided into front and back of the classrooms, not façade near and corridor near.

A typical corridor (length = 119 m) installation consists of 27 luminaires with two 36W tubes each (figure 36). The corridors are additionally centrally controlled that means the lighting can be turned off (except the security light). This is done at night and during weekends.
Some rooms in the Middle School still show the original lighting system with suspended luminaires with inefficient reflectors and only turn on and off control (Figure 37). The ballasts are exchanged as they fail (not on a regular schedule).

![Figure 37. Original suspended luminaire lighting system.](image)

6.6 Problems/Damages

During the building inspection the following problems were found:

- The windows include only one sealing lip. This leads to water intrusion at the west façade during rain.
- Convectors behind cupboards. As mentioned, in some classrooms of the elementary school cupboards are placed right in front of the heating emission system. Obviously this causes slower heating of the rooms in the morning and more heating losses through the walls.
• Partly inefficient reflectors for lighting. The few remaining old luminaires in the middle school should be replaced by more efficient luminaires with better reflectors.
• Partly inefficient lighting controls (see lighting description).
• In some technical rooms the domestic hot water pipes are installed without insulation throughout the room. This leads to unnecessary high distribution losses.
• The ventilation system of the assembly room of the elementary school has no heat recovery. The whole ventilation system is 40 yrs old, and as would be expected, is very ineffective. For instance, the fans will have a much higher installed power than necessary.
• The glazing is covered with the protective foil. This foil reduces the solar gains and the daylight availability. If the foil is not necessary as sight protection from the outside, but purely as security against glass breakage, it is advised to change to a more transparent foil.
• The computers in the central computer rooms were not turned off, even though the building visit was made at the end of the summer break. It has to be expected that the computers are also not turned off at the end of a school day. Standby losses are considerable as electrical energy has a high primary factor and high costs.
• Ventilation system of the kitchen without heat recovery, therefore unnecessary high ventilation losses.
• The heating system has no weekend or holiday setback mode.
• The insulation of the heat delivery system in the crawl space and at the transfer station of the district heating system is not “state of the art” and is partly damaged, resulting in necessarily higher delivery losses.
• There is no metering system for the schools for heat or electricity. The whole building complex Hainerberg seems to have only one metering system, which makes it difficult to measure and compare energy consumption of specific buildings.

6.7 Evaluation of the Schools within the Energy Concept Adviser

The Energy Concept Adviser can evaluate different configurations of building components, including various heating, ventilation, and lighting systems. For each school building component, the most similar component in ECA was selected to best approximate actual building conditions (Tables 17 and 18).
Table 17. ECA Elementary School configuration.

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Characteristic Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior wall</td>
<td>Concrete sandwich construction</td>
<td>U=0.8 W/m²K</td>
</tr>
<tr>
<td>Flat roof</td>
<td>Concrete, insulation, bituminous sealing</td>
<td>U=0.9 W/m²K</td>
</tr>
<tr>
<td>Base slab</td>
<td>Concrete, screed floor</td>
<td>U=3.3 W/m²K</td>
</tr>
<tr>
<td>Windows</td>
<td>Double glazed, metal frame, not decoupled, no sealing</td>
<td>U=4.0 W/m²K $g=78%$</td>
</tr>
<tr>
<td>Solar shading system</td>
<td>Internal shading system</td>
<td></td>
</tr>
<tr>
<td>Heating and ventilation system</td>
<td>District heating, 90/70 °c, natural ventilation, night set-back</td>
<td></td>
</tr>
<tr>
<td>Lighting system</td>
<td>Fluorescent tubes, manual switch</td>
<td></td>
</tr>
</tbody>
</table>

Table 18. ECA Middle School configuration.

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Characteristic Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior wall</td>
<td>Concrete brick construction</td>
<td>U=1.4 W/m²K</td>
</tr>
<tr>
<td>Pitched roof</td>
<td>Insulation between the rafters, tiles</td>
<td>U=0.6 W/m²K</td>
</tr>
<tr>
<td>Base slab</td>
<td>Concrete, screed floor</td>
<td>U=3.3 W/m²K</td>
</tr>
<tr>
<td>Windows</td>
<td>Double glazed, metal frame, not decoupled, no sealing</td>
<td>U=4.0 W/m²K $g=78%$</td>
</tr>
<tr>
<td>Solar shading system</td>
<td>External shading system</td>
<td></td>
</tr>
<tr>
<td>Heating and ventilation system</td>
<td>District heating, 90/70 °c, natural ventilation, night set-back</td>
<td></td>
</tr>
<tr>
<td>Lighting system</td>
<td>Fluorescent tubes, manual switch</td>
<td></td>
</tr>
</tbody>
</table>

A summary of the used general cost values is given in the following:

- Inflation rate: 2 %
- Interest rate: 3 %
- Energy prices:
  - district heating: fixed price: 410 €/yr, consumption based price: 3.8 €ct/kWh
  - electricity: fixed price: 95 €/yr, consumption based price: 11 €ct/kWh.

The energy prices were requested from the facility manager of the site. They have not been received by the time of the report and might change slightly the results. For now the default values from the ECA tool were taken.
6.8 Energy Consumption of the Existing State

The two buildings are not individually metered; therefore actual energy consumption of the two buildings is unknown. Table 19 lists calculated energy demand.

Table 19. Calculated energy demand of the existing state according to the Energy Concept Adviser.

<table>
<thead>
<tr>
<th>Characteristic Value</th>
<th>Unit</th>
<th>Elementary School</th>
<th>Middle School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor area</td>
<td>m²</td>
<td>12264</td>
<td>6862</td>
</tr>
<tr>
<td>Final heating energy demand</td>
<td>kWh/m²a</td>
<td>359.0</td>
<td>347.1</td>
</tr>
<tr>
<td>Final electricity energy demand</td>
<td>kWh/m²a</td>
<td>6.4</td>
<td>6.0</td>
</tr>
<tr>
<td>Total primary energy demand</td>
<td>kWh/m²a</td>
<td>485.9</td>
<td>469.6</td>
</tr>
<tr>
<td>CO₂ emissions</td>
<td>kg/m²</td>
<td>63.5</td>
<td>61.2</td>
</tr>
</tbody>
</table>

Benchmark values (Table 20) were taken from a national study prepared by Fraunhofer Institute of Building Physics, which gathered energy consumption from schools and university buildings. Energy consumption for more than 300 different schools were collected and statistically analyzed.

Table 20. Benchmarks for German Schools as used in the Energy Concept Adviser.

<table>
<thead>
<tr>
<th>Benchmark Value</th>
<th>Unit</th>
<th>Low</th>
<th>Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating energy consumption</td>
<td>kWh/m²a</td>
<td>88</td>
<td>211</td>
<td>374</td>
</tr>
<tr>
<td>Electrical energy consumption</td>
<td>kWh/m²a</td>
<td>6</td>
<td>20</td>
<td>46</td>
</tr>
</tbody>
</table>

Though consumptions that form the basis of the benchmarks and demands as calculated with the ECA tool are not totally the same (influence of users and weather), the comparison of the data leads to the following assessment:

- Both U.S. schools situated in Hainerberg, Germany have heating energy demands that are much higher than the average of the study and therefore an energy efficiency retrofit is recommended.
- In the case of the electrical energy the benchmark consumptions include more than only the lighting and the auxiliary electrical heating energy as in the calculated ECA electricity demand. However it can be said that the electricity demand of the two buildings is not extreme. Anyway, a better lighting control can lead to better results.
6.9 Retrofit Concepts According to the ECA

For both buildings five different retrofit concepts have been assessed with the Energy Concept Adviser. It has to be mentioned that the ECA offers a list of possible measures for each building and system component that can be combined to retrofit concepts in a second step. It is not a planning tool, but the first rough analysis of suitable retrofit measures for educational buildings. The concepts summarized in this chapter are general. However, the recommendations for retrofit listed in section 6.10 are more building specific and are derived from the experience of the building inspectors (Tables 21 and 22).

Table 21. Elementary School retrofit concepts.

<table>
<thead>
<tr>
<th>Retrofit Measures</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
<th>Concept 4</th>
<th>Concept 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating system: reduction of system temperature to 55/45 °C, new transfer station, zone control, replacement of the DHW storage and the circulation pump</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Windows: new plastic framed windows, double pane with low-e coating and gas filling, U=1.1 W/m²K</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flat roof: 6 cm of insulation below the ceiling</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighting control: occupancy sensors</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exterior wall: 12 cm insulation + plaster on the exterior side</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Solar shading: replace internal shading with external shading system</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 22. Estimated results from implementing Elementary School retrofit concepts.

<table>
<thead>
<tr>
<th>Results</th>
<th>Unit</th>
<th>Existing Building</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
<th>Concept 4</th>
<th>Concept 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final heating energy demand</td>
<td>kWh/m²a</td>
<td>359.0</td>
<td>289.6</td>
<td>360.2</td>
<td>359.0</td>
<td>239.1</td>
<td>108.4</td>
</tr>
<tr>
<td>Final electricity energy demand</td>
<td>kWh/m²a</td>
<td>6.4</td>
<td>6.4</td>
<td>5.0</td>
<td>6.5</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Total primary energy demand</td>
<td>kWh/m²a</td>
<td>485.9</td>
<td>395.0</td>
<td>483.1</td>
<td>485.9</td>
<td>325.7</td>
<td>154.1</td>
</tr>
<tr>
<td>CO₂ emissions</td>
<td>kg/m²a</td>
<td>63.5</td>
<td>52.0</td>
<td>62.9</td>
<td>63.5</td>
<td>42.7</td>
<td>20.7</td>
</tr>
<tr>
<td>Investments</td>
<td>€</td>
<td>-</td>
<td>952000</td>
<td>258000</td>
<td>230000</td>
<td>1905000</td>
<td>2763000</td>
</tr>
<tr>
<td>Static amortization</td>
<td>a</td>
<td>-</td>
<td>19.1</td>
<td>129.2</td>
<td>∞</td>
<td>28.2</td>
<td>15.5</td>
</tr>
</tbody>
</table>
The calculated results for the five different concepts show (Table 23) that the lighting control based on occupancy sensors (Concept 2 and part of concepts 4 and 5) can probably not be realized in a cost-efficient way. The windows, the flat roof insulation and the insulation on the exterior wall are interesting measures in terms of energy efficiency but not cost-efficient (Concept 4). In combination with a revised heating system with lower temperatures (Concept 5). The measures are getting cost-efficient if the period of analysis is more than 15 yrs. According to the calculation with the ECA these measures should be further analyzed in a future retrofit project.

The calculated investment costs for Concept 5 are 2.8 million Euros, related to the floor area about 225 €/m². The reduction of the heating energy consumption for this concept is 251 kWh/m² or 3073000 kWh/yr.

The results (Table 24) have to be regarded under the aspect that no anyway measures have been used as basis (renovation measures that need to be done without any energy-efficiency reasons and will therefore reduce the costs of more energy-efficient measures). An example for anyway measures might be the untight windows. Additionally the used energy tariffs are quite low as the default values are taken from the energy tariffs of a municipality with lots of buildings and therefore special tariffs.

<table>
<thead>
<tr>
<th>Retrofit measures</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
<th>Concept 4</th>
<th>Concept 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellar ceiling: insulation (6 cm of polystyrene below the ceiling)</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Exterior wall: 12 cm insulation + plaster on the exterior side</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating system: reduction of system temperature to 55/45 °C, new transfer station, zone control, replacement of the DHW storage and the circulation pump</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Windows: new plastic framed windows, double pane with low-e coating and gas filling, U=1.1 W/m²K</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Lighting control: occupancy sensors</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shading system: New external shading system</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Table 24. Estimated results from implementing Middle School retrofit concepts.

<table>
<thead>
<tr>
<th>Results</th>
<th>Unit</th>
<th>Existing Building</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
<th>Concept 4</th>
<th>Concept 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final heating energy demand</td>
<td>kWh/m²a</td>
<td>347.1</td>
<td>262.4</td>
<td>348.2</td>
<td>203.0</td>
<td>129.7</td>
<td>131.1</td>
</tr>
<tr>
<td>Final electricity energy demand</td>
<td>kWh/m²a</td>
<td>6.0</td>
<td>6.0</td>
<td>4.6</td>
<td>6.0</td>
<td>5.3</td>
<td>4.0</td>
</tr>
<tr>
<td>Total primary energy demand</td>
<td>kWh/m²a</td>
<td>469.6</td>
<td>359.0</td>
<td>466.4</td>
<td>283.0</td>
<td>184.4</td>
<td>182.4</td>
</tr>
<tr>
<td>CO₂ emissions</td>
<td>kg/m²</td>
<td>61.2</td>
<td>47.2</td>
<td>60.6</td>
<td>37.5</td>
<td>24.8</td>
<td>24.5</td>
</tr>
<tr>
<td>Investments</td>
<td>€</td>
<td>—</td>
<td>682000</td>
<td>144000</td>
<td>877000</td>
<td>1358000</td>
<td>1502000</td>
</tr>
<tr>
<td>Static amortization</td>
<td>a</td>
<td>—</td>
<td>19.7</td>
<td>133.3</td>
<td>15.5</td>
<td>13.0</td>
<td>14.3</td>
</tr>
</tbody>
</table>

Very similar to the calculations for the Elementary School calculated results for the five different concepts show that the lighting control based on occupancy sensors (Concept 2 and part of Concept 5) can probably not be realized in a cost-efficient way. The windows, the cellar ceiling and the insulation on the exterior wall are interesting measures in terms of energy efficiency and cost-efficiency (Concept 3) with about 15-yr static payback time. In combination with a revised heating system with lower temperatures (Concept 4) the measures are getting more cost-efficient and the static amortization is 13 yrs. According to the calculation with the ECA these measures should be further analyzed in a future retrofit project.

The calculated investment costs for Concept 4 are 1.4 million Euros, related to the floor area about 200 €/m². The reduction of the heating energy consumption for this concept is 217 kWh/m²a or 1491000 kWh/yr.

The results have to be regarded under the aspect that no anyway measures have been used as basis (renovation measures that need to be done without any energy-efficiency reasons and will therefore reduce the costs of more energy-efficient measures). An example for anyway measures might be the untight windows. Additionally the used energy tariffs are quite low as the default values are taken from the energy tariffs of a municipality with lots of buildings and therefore special tariffs.

6.10 Recommendations

The retrofit advice given here can be divided into two different types of measures. The first are the measures that seem to be interesting based on
the calculation of the Energy Concept Adviser. The second are the measures that should be realized to improve the problems that were found during the building inspection. Most of these measures cannot be analyzed in detail with the Energy Concept Adviser as they are too building specific. Some of the measures are for building parts that cannot be calculated with the ECA (e.g., the assembly hall, the kitchen and the gym).

6.10.1 Elementary School

- Measures to be evaluated in more detail based on the ECA results:
  Combination of:
  - new windows, double pane with low e-coating and gas filling
    (cheapest solution would be plastic frame), U-value ~ 1.1 W/m²K
  - replacement of internal shading with external shading system
  - additional insulation below the flat roof (uppermost ceiling)
  - insulation on the external wall for example with a composite insulation system (insulation + plaster), ~ 12 cm of polystyrene or mineral wool
  - reduction of the heating system temperature to 55/45 °C, new transfer station of the district heating system, evaluation of a zone control

- Measures to be considered to improve the existing situation (problems):
  - add better sealing to the existing windows or exchange windows with a better quality (sealing and U-value)
  - remove cupboards from the heating emission system (radiators/convectors)
  - improve the efficiency of the ventilation system of the assembly hall
  - remove the protective foil from the glazing. If the foil realizes a safety measure replace with transparent foil
  - turn off the computers completely when not in use
  - add weekend and holiday setback to the heating system
  - start metering all buildings separately to find out where the biggest energy consumers are and how much energy can be saved with low-cost or no-cost measures
  - add a heat recovery system to the ventilation of the kitchen
6.10.2 Middle School

- Measures to be evaluated in more detail based on the ECA results:
  Combination of:
  - new windows double pane with low e-coating and gas-filling (cheapest solution would be plastic frame), U-value ~ 1.1 W/m²K
  - replacement of internal shading with external shading system
  - add insulation below the cellar ceiling
  - insulation on the external wall for example with a composite insulation system (insulation + plaster), ~ 12 cm of polystyrene or mineral wool
  - reduction of the heating system temperature to 55/45 °C, new transfer station of the district heating system, evaluation of a zone control

- Measures to be considered to improve the existing situation (problems):
  - add better sealing to the existing windows or exchange the windows with a better quality (sealing and U-value)
  - replace the partly inefficient lighting reflectors
  - improve the partly inefficient lighting controls
  - improve the efficiency of the ventilation system of the assembly hall (smaller fan motors, add heat recovery)
  - remove the protective foil from the glazing. If the foil realizes a safety measure replace with transparent foil
  - turn off the computers completely when not in use
  - add weekend and holiday setback to the heating system
  - renew/improve the insulation on the heating distribution system in the crawl space and the at the transfer station of the district heating system
  - start metering all buildings separately to find out where the biggest energy consumers are and how much energy can be saved with low-cost or no-cost measures
Table 25. Summary of all ECMs at Wiesbaden Schools.

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings</th>
<th></th>
<th>Thermal Savings</th>
<th></th>
<th>Total Savings</th>
<th></th>
<th>Investment</th>
<th></th>
<th>Simple Payback</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MWh/yr</td>
<td>$K/yr</td>
<td>MWh/yr</td>
<td>$K/yr</td>
<td>$K/yr</td>
<td>$K</td>
<td>yrs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WS1</td>
<td>Elementary School: Heating System, Windows, Roof, Lighting, Walls, Solar Shading</td>
<td>17.2</td>
<td>2.5</td>
<td>3073</td>
<td>151.8</td>
<td>154.3</td>
<td>3592</td>
<td>23.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WS2</td>
<td>Middle School: Windows, Roof, Lighting, Walls, Solar Shading</td>
<td>8.6</td>
<td>1.2</td>
<td>1492</td>
<td>73.7</td>
<td>74.9</td>
<td>1765</td>
<td>23.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Schools</td>
<td>25.8</td>
<td>3.7</td>
<td>4565.2</td>
<td>225.5</td>
<td>229.2</td>
<td>5357.3</td>
<td>23.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7 Summary, Recommendations, and Conclusions

7.1 Summary

An Energy and Process Optimization Assessment (EPOA) study was conducted at selected U.S. Army Installations, which included Keiserslautern Army Depot, Piermasens Army Depot, Katterbach Kaserne, and Storck Barracks in Illesheim. Additionally, a brief assessment visits were made to the U.S. Army Germersheim Army Depot and a warehouse complex Big-O at Defense Distribution Depot Europe (DDDE), and at the U.S. Army Garrison Grafenwoehr to identify potential for energy conservation at those locations. A separate energy assessment analysis of two U.S. Army Garrison Wiesbaden Schools using energy concept adviser (ECA) developed by the IEA ECBCS Programme Annex 36 was performed at later time and its results are included in this report.

Eighty five Energy Conservation Measures (ECMs) addressing Central Energy Plants and distribution systems, Building envelopes, Compressed Air Systems, HVAC, Electrical and Lighting technologies were identified and most of them were quantified economically. If implemented, these ECMs would reduce annual electrical energy consumption by approximately 2412 MWh, thermal heating consumption by 17277 MWh, total operating costs (energy, maintenance and labor) by approximately $1.4 million/yr.

Implementation of these ECMs (Table 26) would cost approximately $9.7 million and would yield an average simple payback of 7.2 yrs. It is recommended that these potential cost savings be aggressively pursued with a program of energy and process optimization and that the 34 low cost/no risk measures be funded internally as soon as possible.

Implementation of 43 moderate cost/low risk ECMs with a higher investment requirements (between $20K and $1 million) will yield annual savings of $989,000, and will require $4.1 million in investments, which will yield a simple payback of 4.2 yrs. (Some of these complex ECMs may require SME support to provide 30 percent design.) These ECMs can be im-
plemented either using central funding or third part financing mechanisms: Energy Savings Performance Contracts (ESPC) or Utility Energy Services Contracts (UESC).

The ECMs for the Wiesbaden Schools show a payback about 23 yrs; it is recommended that the ECMs be implemented when other retrofit non-energy related projects are planned, or by using ESPC or UESC mechanisms.

This study recommends a separate Level I EPOA assessment of the industrial complex at the Germersheim DDDE and a Level II EPOA assessment at the flight simulator building in Illesheim, since both those locations have a potential to significantly reduce energy use and operating costs, and to improve worker productivity.

The 72 ECMs at Keiserslautern and Pirmasens AD, summarized in Table 27, would reduce electrical consumption by approximately 2,386 MWh, thermal heating consumption by 11,594 MWh, total operating costs (energy, maintenance and labor) by approximately $1.1 million/yr; these ECMs would cost $3.85 million and would yield an average simple payback of 3.5 yrs.

<table>
<thead>
<tr>
<th>Table 26. Summary of all ECMs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECM Category</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>Lighting - Kaiserslautern and Pirmasens</td>
</tr>
<tr>
<td>Building Envelope - Kaiserslautern</td>
</tr>
<tr>
<td>Compressed Air - Kaiserslautern</td>
</tr>
<tr>
<td>Electrical – Kaiserslautern</td>
</tr>
<tr>
<td>HVAC – Kaiserslautern</td>
</tr>
<tr>
<td>Building Envelope - Pirmasens</td>
</tr>
<tr>
<td>District Heating – Pirmasens</td>
</tr>
<tr>
<td>Electrical Pirmasens</td>
</tr>
<tr>
<td>HVAC - Pirmasens</td>
</tr>
<tr>
<td>HVAC-Ansbach area: Katterbach and Illesheim</td>
</tr>
<tr>
<td>Wiesbaden Schools</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
Table 27. Summary of all ECMs at Keiserslautern and Pirmasens AD.

<table>
<thead>
<tr>
<th>ECM Category</th>
<th>Chapter</th>
<th># ECMs</th>
<th>Electrical Savings</th>
<th>Thermal Savings</th>
<th>Additional Savings</th>
<th>Total Savings</th>
<th>Investment</th>
<th>Simple Payback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting - Kaiserslautern and Pirmasens</td>
<td>4.2</td>
<td>18</td>
<td>367</td>
<td>29.5</td>
<td>0</td>
<td>29.5</td>
<td>36.8</td>
<td>1.25</td>
</tr>
<tr>
<td>Building Envelope – Kaiserslautern</td>
<td>4.3</td>
<td>15</td>
<td>3,702</td>
<td>241</td>
<td>70</td>
<td>311</td>
<td>1,856</td>
<td>6</td>
</tr>
<tr>
<td>Compressed Air – Kaiserslautern</td>
<td>4.4</td>
<td>1</td>
<td>203</td>
<td>16</td>
<td></td>
<td>16</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>Electrical – Kaiserslautern</td>
<td>4.5</td>
<td>1</td>
<td>37</td>
<td>3</td>
<td></td>
<td>3</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>HVAC – Kaiserslautern</td>
<td>4.6</td>
<td>26</td>
<td>1632.4</td>
<td>82.3</td>
<td>3734</td>
<td>475</td>
<td>1433.2</td>
<td>3</td>
</tr>
<tr>
<td>Building Envelope – Pirmasens</td>
<td>4.7</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>514</td>
<td>33</td>
<td>162</td>
<td>4.9</td>
</tr>
<tr>
<td>District Heating – Pirmasens</td>
<td>4.8</td>
<td>1</td>
<td>102</td>
<td>48</td>
<td>1,019</td>
<td>48</td>
<td>20</td>
<td>0.4</td>
</tr>
<tr>
<td>Electrical Pirmasens</td>
<td>4.9</td>
<td>1</td>
<td>25</td>
<td>2</td>
<td></td>
<td>2</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>HVAC – Pirmasens</td>
<td>4.10</td>
<td>5</td>
<td>122</td>
<td>10</td>
<td>2,625</td>
<td>172</td>
<td>182</td>
<td>335</td>
</tr>
<tr>
<td>Total</td>
<td>72</td>
<td>2386.4</td>
<td>142.8</td>
<td>11594</td>
<td>494</td>
<td>186.6</td>
<td>1099.5</td>
<td>3845</td>
</tr>
</tbody>
</table>

The 11 primarily HVAC-related ECMs at Katterbach and Illesheim (described in Chapter 5 and summarized in Table 26) would reduce thermal heating consumption by 1,117,300 MWh, operating costs by approximately $74,5000/yr, cost $481000, and would yield an average simple payback of 6.5 yrs.

Energy conservation concepts developed for the two Wiesbaden Schools (described in Chapter 6 and summarized in Table 26) would reduce electrical consumption by approximately 25.8 Mwh, thermal heating consumption by 4565.2 MWh, and total operating costs by approximately $275,000/yr; these concepts would cost $5.4 million and yield an average simple payback of 23.4 yrs.

7.2 Recommendations

The Level I analysis of multiple complex systems conducted during the EPOA are not intended to be (nor should they be) precise. The quantity and quality of the systems improvement identified suggests that sufficient potential exists. It is recommended that these potential cost savings be aggressively pursued. It is also recommended that the low cost/no risk (so-called “slam dunk”) ECMs that can typically be implemented quickly (summarized in Table 28) be funded internally and implemented as soon as possible. All 34 ECMs in this table require an investment of $95K and would yield an average simple payback of about 0.8 yr. Together they have potential to save $118K/yr. All lighting projects under this category can be implemented as a one project.
Table 28. Summary of low-cost/no-risk ECMs.

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings</th>
<th>Thermal Savings</th>
<th>Total Savings</th>
<th>Investment $</th>
<th>Simple Payback yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MWh/yr</td>
<td>$K/yr</td>
<td>MWh/yr</td>
<td>$K/yr</td>
<td></td>
</tr>
<tr>
<td>LI1-LI18</td>
<td>Kaiserslautern and Pirmasens Lighting ECMs</td>
<td>367 29.5</td>
<td>0</td>
<td>0</td>
<td>29.5</td>
<td>36.8</td>
</tr>
<tr>
<td>BE6</td>
<td>Repair door seals, building 2226</td>
<td></td>
<td>9.7 0.63</td>
<td>0.63</td>
<td>2</td>
<td>3.2</td>
</tr>
<tr>
<td>BE8</td>
<td>Place insulated panel in unused door areas in building 2371</td>
<td>51.8 3.4</td>
<td>3.4</td>
<td>7.2</td>
<td>2</td>
<td>2.1</td>
</tr>
<tr>
<td>BE9</td>
<td>Repair damaged doors in building 2371</td>
<td></td>
<td>9.7 0.6</td>
<td>0.6</td>
<td>1</td>
<td>1.6</td>
</tr>
<tr>
<td>BE14</td>
<td>Repair door seals, building 2370</td>
<td></td>
<td>9.6 0.6</td>
<td>0.6</td>
<td>2</td>
<td>3.2</td>
</tr>
<tr>
<td>BE17</td>
<td>Close Opening Above Crane Using Brushes and Rubber Strips, Building 4000</td>
<td>19 1.2</td>
<td>1.2</td>
<td>1.6</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>BE18</td>
<td>Close Openings in Carpenter Storage Room, Building 4000</td>
<td></td>
<td>10 0.6</td>
<td>0.6</td>
<td>1</td>
<td>1.6</td>
</tr>
<tr>
<td>CA1</td>
<td>Turn Off Air Compressors on Weekends and Nights Building 2224</td>
<td>203 16.2</td>
<td>16.2</td>
<td>1.5</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>EL1</td>
<td>Switch off Computers When Not In Use -- Bldg 2233</td>
<td>36.8 2.9</td>
<td>2.9</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>EL2</td>
<td>Switch off Computers When Not In Use Building 4000</td>
<td>24.5 2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>HV4</td>
<td>Replace fans and Lengthen Duct on Heat Recovery Unit for Dynamometers 1 to 3</td>
<td>36.3 2.4</td>
<td>2.4</td>
<td>12</td>
<td>5.1</td>
<td></td>
</tr>
<tr>
<td>HV6</td>
<td>Reduce Excessive Air Use in Welding and Vehicle Exhaust Building 2233</td>
<td>46.4 3.7</td>
<td>3.7</td>
<td>7.5</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>HV13</td>
<td>Place Thermostat Controls Away From Occupants. Improved Control For Air Heaters</td>
<td>105 8.4</td>
<td>8.4</td>
<td>0.2</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>HV21</td>
<td>Have Heating Utility Turn off Heat to Buildings when not Warranted</td>
<td></td>
<td></td>
<td></td>
<td>Immediate</td>
<td></td>
</tr>
<tr>
<td>HV22</td>
<td>Use Heat from Generator Test for Building Heat, Building 2362</td>
<td>78 5.1</td>
<td>5.1</td>
<td>5.1</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>HV24</td>
<td>Provide Better Controls Of H&amp;V In Building 2371</td>
<td>365 29.2</td>
<td>29.2</td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>HV25</td>
<td>Insulate Heating System Components-Building 2371</td>
<td></td>
<td></td>
<td></td>
<td>&lt; 2 yrs</td>
<td></td>
</tr>
<tr>
<td>HV26</td>
<td>Provide Temperature Control Of Unit Heaters In Building 2281</td>
<td>0 180</td>
<td>11.7</td>
<td>11.7</td>
<td>7</td>
<td>0.6</td>
</tr>
<tr>
<td>Total 35 ECMs</td>
<td></td>
<td>1147.7 91.9</td>
<td>1004.1</td>
<td>26.23</td>
<td>118.13</td>
<td>94.8</td>
</tr>
</tbody>
</table>

Table 29 summarizes 43 moderate cost/low risk ECMs with a higher investment requirements (between $20K and $1 million). If implemented, these ECMs will together result in annual savings of $989 thousand, will require $4.1 million in investments, and will yield a simple payback of 4.2 yrs. (Some of these complex ECMs may require SME support to provide 30% design.) All projects which propose replacement of unit and other warm air heating systems with hydronic radiant panels are recommended to be packaged and implemented as a one project.
Table 29. Summary of moderate cost/low risk ECMs.

<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings MWh/yr</th>
<th>$K/yr</th>
<th>Thermal Savings MWh/yr</th>
<th>$K/yr</th>
<th>Additional Savings $K/yr</th>
<th>Total Savings $K/yr</th>
<th>Investment $K</th>
<th>Simple Payback yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE1</td>
<td>Use transparent plastic panels behind glass sash, building 2233</td>
<td>2569</td>
<td>167</td>
<td>167</td>
<td>1052</td>
<td>6.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE2</td>
<td>a. Reduce solar heat load by use of conventional solar 1 film or</td>
<td>70</td>
<td>70</td>
<td>280</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE3</td>
<td>Add vestibule on west side door of building 2233</td>
<td>137</td>
<td>8.9</td>
<td>105</td>
<td></td>
<td>11.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE5</td>
<td>Provide insulated panels for door openings in building 2222</td>
<td>28.3</td>
<td>1.84</td>
<td>16.8</td>
<td></td>
<td>9.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE7</td>
<td>Add vestibule on west side of building going-up ramp in building 2371</td>
<td>145</td>
<td>9.4</td>
<td>50.4</td>
<td></td>
<td>5.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE10</td>
<td>Insulate north wall blog 2371</td>
<td>49.8</td>
<td>3.2</td>
<td>22.5</td>
<td></td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE11</td>
<td>Use transparent plastic panels behind glass windows building 2281</td>
<td>158</td>
<td>10.3</td>
<td>64.7</td>
<td></td>
<td>6.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE12</td>
<td>Use transparent plastic panels to replace roof skylights building 2281</td>
<td>118</td>
<td>7.7</td>
<td>70.4</td>
<td></td>
<td>9.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE13</td>
<td>Repair and insulate roof building 2281</td>
<td>372</td>
<td>24.2</td>
<td>149.6</td>
<td></td>
<td>6.2</td>
<td></td>
<td></td>
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<tr>
<td>BE15</td>
<td>Insulate roof in maintenance building #2226</td>
<td>44.8</td>
<td>2.9</td>
<td>32.8</td>
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<td>11.3</td>
<td></td>
<td></td>
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<tr>
<td>BE16</td>
<td>Install Drop Ceiling in Certain Spaces, Building 4000</td>
<td>22</td>
<td>1.4</td>
<td>32.7</td>
<td></td>
<td>23.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE19</td>
<td>Add Wall Insulation, Building 4171</td>
<td>464</td>
<td>30.2</td>
<td>127</td>
<td></td>
<td>4.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV2</td>
<td>Install Exhaust Fans To Ventilate Building 2233</td>
<td>116.6</td>
<td></td>
<td>65</td>
<td></td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV3</td>
<td>Install Destratification Fans Recover Heat in Upper Strata – Building 2233</td>
<td>700</td>
<td>45.5</td>
<td>40</td>
<td></td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV5</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2233</td>
<td>6.06</td>
<td>98.5</td>
<td>459.9</td>
<td></td>
<td>4.7</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HV7</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213</td>
<td>95</td>
<td>6.2</td>
<td>33.95</td>
<td></td>
<td>5.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV8</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213</td>
<td>24</td>
<td>15.6</td>
<td>97.9</td>
<td></td>
<td>6.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV9</td>
<td>Recirculate Exhaust Air Back into Booth During Drying Operations, Building 2225</td>
<td>59</td>
<td>3.8</td>
<td>20</td>
<td></td>
<td>5.2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HV10</td>
<td>Replace heaters, insulate roof and improve usage of the heat exchange station in Warehouse, Building #2238</td>
<td>185.6</td>
<td>12.06</td>
<td>98.42</td>
<td></td>
<td>8.2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HV11</td>
<td>Replace heaters, insulate roof and improve usage of the heat exchange station in Warehouse, Building #2239</td>
<td>283.5</td>
<td>18.43</td>
<td>145.5</td>
<td></td>
<td>7.9</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HV14</td>
<td>Increase Ventilation to Reduce Solvent Furnes in Space-Building 2222</td>
<td></td>
<td></td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HV15</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop Building 2225</td>
<td>76.5</td>
<td>4.4</td>
<td>31.75</td>
<td></td>
<td>7.2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HV16</td>
<td>Provide Heaters over Doors on South Side-Building 2226</td>
<td></td>
<td></td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HV17</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2226</td>
<td>120</td>
<td>7.8</td>
<td>54.5</td>
<td></td>
<td>7</td>
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<td></td>
<td></td>
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<tr>
<td>ECM</td>
<td>ECM Description</td>
<td>Electrical Savings</td>
<td>Thermal Savings</td>
<td>Additional Savings</td>
<td>Total Savings</td>
<td>Investment</td>
<td>Simple Payback yrs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>---------------------------------------------------------------------------------</td>
<td>--------------------</td>
<td>----------------</td>
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<td>------------</td>
<td>-------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>MWh/yr</td>
<td>$K/yr</td>
<td>MWh/yr</td>
<td>$K/yr</td>
<td>$K</td>
<td>yrs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV18</td>
<td>Separate the Building Heating System from the Boiler and Connect the Building to District Heating System at Apprentice Shop, Building # 2364</td>
<td>~25%</td>
<td>~25%</td>
<td></td>
<td></td>
<td></td>
<td>&lt; 5 yrs</td>
<td></td>
<td></td>
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<tr>
<td>HV19</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Apprentice Shop, Building # 2363</td>
<td>75</td>
<td>4.9</td>
<td>4.9</td>
<td>39.3</td>
<td>8.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV20</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop, Building # 2372</td>
<td>190</td>
<td>11.4</td>
<td>11.4</td>
<td>53.25</td>
<td>4.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV23</td>
<td>Provide Door Heater at Door on East Side of Building 2371</td>
<td>36</td>
<td>2.3</td>
<td>2.3</td>
<td>25</td>
<td>10.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEP1</td>
<td>Turn Off District Heating To Buildings In Summer</td>
<td>1019</td>
<td>47.9</td>
<td>47.9</td>
<td>20</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV27</td>
<td>Improve HVAC System Controls Building 4000</td>
<td>0</td>
<td>1000</td>
<td>65</td>
<td>150</td>
<td>2.3</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HV28</td>
<td>Install Door Heater, Building 4155</td>
<td>13</td>
<td>0.8</td>
<td>0.8</td>
<td>25</td>
<td>29.6</td>
<td></td>
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<tr>
<td>HV29</td>
<td>Improve H&amp;V System Controls and Air Movement In Building 4171, Pirmasens</td>
<td>105</td>
<td>8.4</td>
<td>26</td>
<td>34.4</td>
<td>20</td>
<td>0.6</td>
<td></td>
<td></td>
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<tr>
<td>HV30</td>
<td>Install Economizers, Building 4111, Pirmasens</td>
<td>0</td>
<td>799.2</td>
<td>40</td>
<td>90</td>
<td>2.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV32</td>
<td>Install Measurement Equipment, Building 4111</td>
<td>16.5</td>
<td>1.3</td>
<td>812.5</td>
<td>41.9</td>
<td>50</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV33</td>
<td>Heating system improvement in Commissary at Katterbach Building 5805</td>
<td>–</td>
<td>45.3</td>
<td>3.7</td>
<td>3.7</td>
<td>22</td>
<td>5.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV35</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5801</td>
<td>149</td>
<td>8.94</td>
<td>8.94</td>
<td>59.75</td>
<td>6.7</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>HV36</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5802</td>
<td>90</td>
<td>5.9</td>
<td>5.9</td>
<td>40</td>
<td>6.7</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HV37</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5508</td>
<td>–</td>
<td>100</td>
<td>6</td>
<td>6</td>
<td>40</td>
<td>6.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV38</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5807</td>
<td>–</td>
<td>107</td>
<td>6.42</td>
<td>6.42</td>
<td>50</td>
<td>7.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV39</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5806</td>
<td>–</td>
<td>–</td>
<td>80</td>
<td>4.8</td>
<td>62</td>
<td>12.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV40</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6500</td>
<td>–</td>
<td>–</td>
<td>269</td>
<td>16.14</td>
<td>79</td>
<td>4.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV41</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6501, 6502</td>
<td>–</td>
<td>–</td>
<td>142</td>
<td>8.52</td>
<td>45</td>
<td>5.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HV42</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6502</td>
<td>–</td>
<td>–</td>
<td>235</td>
<td>14.1</td>
<td>83</td>
<td>5.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total 43 ECMs</td>
<td>10720</td>
<td>793</td>
<td>187</td>
<td>989</td>
<td>4144</td>
<td>4.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
All moderate cost ECMs can be implemented either using central funding or third party financing mechanism (e.g., Energy Savings Performance Contracts [ESPC] or Utility Energy Services Contracts [UESC]). It is also recommended that the energy projects at Wiesbaden schools (WS-1 and WS-2) be implemented together with other planned retrofit non-energy related projects, or by using ESPC or UESC mechanisms.

Improvements in energy systems providing support to flight simulator building in Illesheim show a significant potential to save energy and reduce operation costs (HV #43). However, this project will require a more detailed (Level II) assessment. A separate Level I EPOA study of the industrial complex at the Germersheim DDDE is recommended, since it may potentially reduce energy use and operating costs significantly, and improve workers productivity.

Energy conservation projects for Continental U.S. (CONUS) based installations shall be based on current U.S. codes and standards. However, implementation of the Army Energy Strategy, EPAct 2005 and Executive Order 13423 require a more aggressive approach. New construction and retrofit projects for European locations follow host countries’ energy requirements, which are sometimes more stringent than those for the United States. Appendix D contains (an English version of) some current German standards and guidelines concerning energy conservation. This information may be helpful for projects at both CONUS and outside continental U.S. (OCONUS) locations.

### 7.3 Conclusions

An EPOA is a complex undertaking. Several key elements require significant attention to guarantee success: (1) the involvement of key facility personnel who know what the problems are, where they are, and have thought of many solutions; (2) the facility personnel sense of “ownership” of the ideas, which in turn develops a commitment for implementation; and (3) the EPOA focus on site-specific, critical cost issues, which, if solved, will make the greatest possible economic contribution to facility’s bottom-line. Major cost issues are: facility utilization (bottlenecks), maintenance and repair optimization (off-spec, scrap, rework), labor (productivity, planning/scheduling), energy (steam, electricity, compressed air), waste (air, water, solid, hazardous), equipment (outdated or state-of-the-
art), etc. From a cost perspective, facility capacity, materials, and labor utilization are far more significant than energy and environmental concerns. However, all of these issues must be considered together to achieve DOD’s mission of military readiness in the most efficient, cost-effective way. The Energy Assessment Protocol developed by CERL in collaboration with a number of government, institutional, and private sector parties is based on the analysis of the information available from literature, training materials, documented and non-documentation of practical experiences of contributors, and successful showcase energy assessments conducted by a diverse team of experts at the U.S. Army facilities. The protocol addresses both technical and non-technical, organizational capabilities required to conduct a successful assessment geared to identifying measures that can reduce energy and other operating costs without adversely impacting product quality, safety, morale, or the environment.

Expertise in energy auditing is not an isolated set of skills, methods, or procedures; it requires a combination of skills and procedures from different fields. However, an energy and process audit requires a specific talent for putting together existing ways and procedures to show the overall energy performance of a building and the processes it houses, and how the energy performance of that building can be improved. A well-grounded energy and process audit team should have expertise in the fields of heating, ventilating, and air conditioning (HVAC), structural engineering, electrical and automation engineering and, of course, a good understanding of production processes.

Most of the knowledge necessary for energy audit is a part of already existing expertise. Designers, consultants, contractors, and material and equipment suppliers should be familiar with the energy performance of the specific field in which they are experts. Structural designers and consultants should be familiar with heat losses through the building shell and what insulation should be added. Heating and ventilation engineers should be familiar with the energy performance of heating, ventilation, compressed air, and heat recovery systems. Designers of electrical systems should know energy performance of different motors, VFD drives and lighting systems. An industrial process and energy audit requires knowledge of process engineers specialized in certain processes.
Critical to any energy and process audit team member is the ability to apply a “holistic” approach to the energy sources and sinks in the audited target (installation, building, system, or their elements), and the ability to “step out-side the box.” This ability presumes a thorough understanding of the processes performed in the audited building, and of the needs of the end users. For this reason, the end users themselves are important members of the team. It is critical for management, production, operations and maintenance (O&M) staff, energy managers, and on-site contractors to “buy-in” to the implementation by participating in the process, sharing knowledge and expertise, gathering information, and developing ideas.
Appendix A: Assessments at U.S. Army Germersheim Army Depot, Defense Distribution Depot Europe (DDDE), and U.S. Army Garrison Grafenwoehr

In addition to energy assessment conducted by the team at four Army installations, Keiserslautern, Pirmasens, Ansbach, and Illesheim, on the request from IMCOM European Region energy manager, Mr. David Yacoub, Dr. Alexander Zhivov from ERDC CERL had a brief visits to U.S. Army Germersheim Army Depot and a warehouse complex Big-O at Defense Distribution Depot Europe (DDDE), and to the U.S. Army Garrison Grafenwoehr to assess energy conservation opportunities and to collect “lessons learned” from on-going new construction to be used in similar projects. This appendix summarizes these visits.

**U.S. Army Germersheim Army Depot and A Warehouse Complex Big-O at Defense Distribution Depot Europe (DDDE)**

This complex has a number of warehouses, some of which were recently renovated, other are considered for retrofits. Some of newly renovated warehouses have daylighting and high efficient fluorescent lights installed (Figure E1)

![Figure E1. Warehouse daylighting.](image-url)
Some warehouses have plastic “speed doors” operating via motion driven sensors (Figure E2). These doors allow personnel while on forklifts, to move from one warehouse to another without taking time to open and close doors and living these doors open only during the minimum required time.

This energy conservation technology is installed so far only in Building 7972 and it is planned to have similar “speed doors” installed throughout DDDE.

Heating systems used in warehouses are either central air or unit air heating systems with a hot water heating coils. They are not efficient, create temperature stratification along the heights and poor performance close to open doors. Energy conservation can be achieved if these systems are replaced with radiant heating systems (Figure E3).
Studies conducted by Senergy GmbH analyzed and proposed heating concepts for DDDE considering different heating systems (high and low temperature radian heating) and heat generation options (local gas, oil and biomass based and low temperature hot water district heating).

A separate study may be recommended to improve energy performance of the industrial complex at the U.S. Army Depot with following issues to be addressed: poor lighting systems with a potential to a hybrid lighting, radiant heating system for a high bay, “speed doors” at the high traffic entrances, building envelope insulation, evaporative cooling to reduce indoor air temperature during peak summer loads and to improve soldiers productivity and morale (Figure E4).
**U.S. Army Garrison Grafenwoehr**

The focus of the assessment was on new tactical equipment maintenance facilities (TEMF) and new and retrofitted barrack buildings. By the time of the visit, the first out of 12 new TEMF facilities was constructed (Figure E5).

![Figure E5. Tactical equipment maintenance facility.](image)

New TEMF has four individual bays, equipped with underfloor vehicle exhaust systems and an overhead warm air unit heaters. There is no general ventilation and the intend is to ventilate facilities by opening doors.

Vehicle exhausts have a standard coupling to vehicle exhausts, and will be difficult to use with different types of Army vehicles to be serviced. Changeable nozzles designed for each type of vehicles will be more efficient (Figure E6).

![Figure E6. Changeable nozzles designed different vehicle types.](image)

Overhead systems will be easier to use, since they don’t take a floor space, e.g., flexible/multifunctional vehicle exhausts on a boom or an exhaust ail (Figure E7).
Warm air heating systems are inefficient (especially in spaces obstructed by large vehicles). Heating from a hot water district heating system can be done cheaper and more efficient and provide better work environment, if a floor radiant heating system is used for newly constructed TEMF. Radiant floor heating was successfully used at Fort Lewis (Figure E8).

General ventilation is needed (especially during colder times of the year). To preheat supply air a solar wall technology can be used (Figure E9).
Lighting systems in both TEMF and in sheds shall operate with a sensor to turn them off when the sun is shining (Figure E10).

![Figure E10. Example lighting systems with solar sensors.](image)

Hybrid lighting in TEMF (a combination of solar tubes and efficient lights) can be incorporated in the design for new construction (Figure E11).

![Figure E11. Example hybrid lighting.](image)

One visited hangars was recently insulated using an Energy Savings Performance Contract (ESPC) contract (Figure E12). Door seals were improved. However, central warm air heating system was not changed and is inefficient (warm air is supplied with low velocities in the upper zone and return is located in the lower zone).
This defect can be avoided in an energy project in the similar adjacent hangar if/when approved and funded (Figure E13).

New Army barracks construction and retrofits are performed having stringent German and European thermal energy performance guidelines in mind. Table 1 lists requirements for heat flux resistance, and Figure E14 shows German requirements to the building air tightness.
Table E28. Requirements for heat flux resistance.

<table>
<thead>
<tr>
<th>Line</th>
<th>Components</th>
<th>Heat flux resistances $R$ in (m²·K)/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Exterior walls; common rooms walls toward basement rooms; passages, open corridor, garages, ground</td>
<td>1.2 $^a$</td>
</tr>
<tr>
<td>2</td>
<td>Walls between external rooms, flat walls</td>
<td>0.07</td>
</tr>
<tr>
<td>3</td>
<td>Stairwell walls</td>
<td>To stairwells with considerably lower indoor temperatures (e.g. indirectly heated stairwell), indoor temperature $T_i \leq 10^\circ$C, stairwell shall be at least without frost</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>To stairwells with indoor temperature $T_i &gt; 10^\circ$C (e.g. administrative buildings, commercial, school buildings, hotels, restaurants and residential building)</td>
</tr>
<tr>
<td>5</td>
<td>Flat walls, ceilings between external workrooms; ceilings underneath rooms between insulated conical roofs and walls in adjacent rooms in case of completed attics</td>
<td>In general</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>In central heated office buildings</td>
</tr>
<tr>
<td>7</td>
<td>Under closure common rooms without basement</td>
<td>Directly at the ground up to a room depth of 5 m</td>
</tr>
<tr>
<td>8</td>
<td>Ceiling underneath non-completed attics; ceilings underneath rooms which allow creeping and rooms which are still smaller; ceilings underneath ventilated rooms between conical roofs and walls in adjacent rooms in case of completed attics, insulated conical roofs</td>
<td>Above a non-ventilated hollow space adjacent to this ground</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Basement ceiling, ceiling toward closed, unventilated corridors and others</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>ceilings (also roofs) which isolate the common rooms from the ambient air</td>
<td>down, towards passages (also heated), passages (also closed) and creep basement capable to ventilating$^b$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>upwards, roofs and ceilings underneath terraces etc.</td>
</tr>
</tbody>
</table>

$^a$ For buildings with lower indoor temperature $T_i \leq 10^\circ$C: $R = 0.55$ (m²·K)/W

$^b$ Increased heat flux resistances because of floor coldness.

- **DIN 4108-2**

  The joint permeability coefficient concerning the connection joints of the building components resulting from measurements must be less than 0.1 m³/m²/h (daPa $^{20}$).

  In case of windows and window doors the requirements acc. to DIN 18055 shall be applied.

  In case of outer doors the joint permeability coefficient must be a $\leq$ 2.0 m³/m²/h (daPa $^{20}$).

- **DIN 4108-7**

  If measurements of the air tightness of buildings are building components are made, the measured air volume flow considering the pressure difference between inside and outside of 50 Pa

  - in case of buildings without HVAC systems:
    - depending on the air volume should not exceed 3h$^{-1}$
    - depending on the net base-area should not exceed 7.8 m³/(m² h)

  - in case of buildings with HVAC system (also exhaust air installation):
    - depending on the air volume should not exceed 1.5h$^{-1}$
    - depending on the net base-area should not exceed 3.9 m³/(m² h)

**Figure E14. German requirements to the building air tightness.**

Figure E15 shows materials used both in new construction and retrofits. Wall insulation level is $U = 0.035$ W/m²·K (brick 12cm+ insulation 14cm + wall blocks 23cm); roof is insulated using the same insulation material.
Figure E15. Insulation materials used in new construction and retrofits.

For new windows $U = 0.9 - 1.4 \text{ W/m}^2\text{K}$, which replace existing windows with $2.5 \text{ W/m}^2\text{K}$ (Figure E16).

Figure E16. New windows with improved insulating characteristics.

Barracks attic space is used for storage (space utilization and reduced heat losses/gains) (Figure E17).
Heating is provided by central low temperature hot water heating system connected to room radiators with an individual thermostat (Figure E18).

Hot water pipes for heating and domestic hot water supply are well insulated (Figure E19).
Entrance doors to individual apartments have keyless entry (Figure E20), which potentially can be linked to controls turning off electrical equipment when apartment is not occupied and setting back radiators’ thermostats.

![Keyless entry doors](image)

**Figure E20. Keyless entry doors.**

Closets are ventilated (Figure E21), which reduces odor and mold issues and result in a superior indoor air quality.

![Ventilated closet](image)

**Figure E21. Ventilated closet.**
Appendix B: Summary of Energy Conservation Measures
<table>
<thead>
<tr>
<th>ECM</th>
<th>ECM Description</th>
<th>Electrical Savings</th>
<th>Thermal Savings</th>
<th>Additional Savings ($K/yr)</th>
<th>Total Savings ($K)</th>
<th>Investment ($K)</th>
<th>Simple Payback (yrs)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>LI1</td>
<td>Install Energy Efficient LED Exit Lights - Kaiserslautern and Pirmasens</td>
<td>16</td>
<td>1.3</td>
<td>1.3</td>
<td>10.8</td>
<td>8.2</td>
<td>8.2</td>
<td>K,P</td>
</tr>
<tr>
<td>LI2</td>
<td>Install Occupancy Sensors to Turn off Unnecessary Lighting, All buildings: Restrooms, lunchrooms, etc – Kaiserslautern and Pirmasens</td>
<td>10</td>
<td>0.8</td>
<td>0.8</td>
<td>5</td>
<td>6.2</td>
<td>6.2</td>
<td>K,P</td>
</tr>
<tr>
<td>LI3</td>
<td>Use Daylight Sensors to Turn off Unnecessary Lighting Building 2233 Maintenance Area</td>
<td>37</td>
<td>3</td>
<td>3</td>
<td>2.5</td>
<td>0.8</td>
<td></td>
<td>K</td>
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<tr>
<td>LI4</td>
<td>Use Daylight Sensors to Turn off Unnecessary Lighting, Building 2233 - Engine repair and other areas on the North side</td>
<td>37</td>
<td>2.96</td>
<td>2.96</td>
<td>2.5</td>
<td>0.9</td>
<td></td>
<td>K</td>
</tr>
<tr>
<td>LI5</td>
<td>Install daylight sensors to switch off unnecessary lighting during daylight hours, Building 2281 Warehouse SAK</td>
<td>30</td>
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<td>LI6</td>
<td>Install daylight sensors to switch off unnecessary lighting during daylight hours, Building 4000 Maintenance Area and Bodyshop</td>
<td>37</td>
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<td>2.95</td>
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<td>LI7</td>
<td>Install daylight sensors to switch off unnecessary lighting during daylight hours, Building 4000 Maintenance-Apprentice Workshop</td>
<td>5.21</td>
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<td>LI8</td>
<td>Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 2371 Shipping and receiving</td>
<td>6</td>
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<td>0.5</td>
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<td>LI9</td>
<td>Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 2370 Security warehouse</td>
<td>85</td>
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<td>LI10</td>
<td>Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 2225 Paint booth</td>
<td>4.2</td>
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<td>LI11</td>
<td>Install Occupancy Sensors to Turn off Unnecessary Lighting, Building 4000 Paint booths</td>
<td>8.4</td>
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<td>LI12</td>
<td>Turn off Halogen Lights When Stacker is not in Use, Building 2281 Stacker lights</td>
<td>5.2</td>
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<td>LI13</td>
<td>Replace Mercury Vapor Lamp with More Efficient Type, Building 2371</td>
<td>33</td>
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<td>LI14</td>
<td>Replace Mercury Vapor Lamp with More Efficient Type, Building 2370</td>
<td>9</td>
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<td>LI15</td>
<td>Replace Mercury Vapor Lamp with More Efficient Type, Building 2213</td>
<td>8</td>
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<td>LI16</td>
<td>Replace Mercury Vapor Lamp with More Efficient Type, Building 4171</td>
<td>17</td>
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<td>LI17</td>
<td>Replace Fluorescent Lamp with More Efficient Type, Building 4171 Warehouse:</td>
<td>10</td>
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<td>LI18</td>
<td>Install Energy Efficient Lighting in Renovations, Building 4155 (under renovation) and other buildings</td>
<td>8.64</td>
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<td>LI191</td>
<td>Improve Lighting Efficiency in Hangars</td>
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<td>BE1</td>
<td>Use transparent plastic panels behind glass sash, building 2233</td>
<td>2569</td>
<td>167</td>
<td>167</td>
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<td>BE2</td>
<td>a. Reduce solar heat load by use of conventional solar film OR</td>
<td></td>
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<td>70</td>
<td>280</td>
<td>4</td>
<td>K</td>
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<td></td>
<td>b. spectrally selective solar film</td>
<td>28.8</td>
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<td>72.3</td>
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<td>BE3</td>
<td>Add vestibule on west side door of building 2233</td>
<td></td>
<td>137</td>
<td>8.9</td>
<td>8.9</td>
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<td>11.8</td>
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<td>BE4</td>
<td>Use Light Shelves for Additional Natural Lighting – Building 2233</td>
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<td>BE5</td>
<td>Provide insulated panels for door openings in building 2222</td>
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<td>1.84</td>
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<td>BE6</td>
<td>Repair door seals, building 2226</td>
<td>9.7</td>
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<td>0.63</td>
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<td>BE7</td>
<td>Add vestibule on west side of building going-up ramp in building 2371</td>
<td>145</td>
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<td>9.4</td>
<td>50.4</td>
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<tr>
<td>BE8</td>
<td>Place insulated panel in unused door areas in building 2371</td>
<td>51.8</td>
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<td>BE9</td>
<td>Repair damaged doors in building 2371</td>
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<td>1.6</td>
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<td>BE10</td>
<td>Insulate north wall bldg 2371</td>
<td>49.8</td>
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<td>Use transparent plastic panels behind glass windows building 2281</td>
<td>158</td>
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<td>Use transparent plastic panels to replace roof skylights building 2281</td>
<td>118</td>
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<td>Repair and insulate roof building 2281</td>
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<td>Repair door seals, building 2370</td>
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<td>Insulate roof in maintenance building #2226</td>
<td>44.8</td>
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<td>BE16</td>
<td>Install Drop Ceiling in Certain Spaces, Building 4000</td>
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<td>BE17</td>
<td>Close Opening Above Crane Using Brushes and Rubber Strips, Building 4000</td>
<td>19</td>
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<td>Close Openings in Carpenter Storage Room, Building 4000</td>
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<td>BE19</td>
<td>Add Wall Insulation, Building 4171</td>
<td>464</td>
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<tr>
<td>HV1</td>
<td>Improve Building Heating Controls</td>
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<td>HV2</td>
<td>Install Exhaust Fans To Ventilate Building 2233</td>
<td>116.64</td>
<td>116.6</td>
<td>65</td>
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<td>HV3</td>
<td>Install Destrafication Fans Recover Heat in Upper Strata – Building 2233</td>
<td>700 45.5</td>
<td>45.5</td>
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<td>40</td>
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<td>HV4</td>
<td>Replace fans and Lengthen Duct on Heat Recovery Unit for Dynamometers 1 to 3</td>
<td>36.3 2.4</td>
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<td>12</td>
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<td>HV5</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2233,</td>
<td>6.06 98.5</td>
<td>98.5</td>
<td>459.9</td>
<td>4.7</td>
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<td>HV6</td>
<td>Reduce Excessive Air Use in Welding and Vehicle Exhaust Building 2233</td>
<td>46.4 3.7</td>
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<td>HV7</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213,</td>
<td>95 6.2</td>
<td>6.2</td>
<td>33.95</td>
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<td>HV8</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Warehouse Building 2213,</td>
<td>24 15.6</td>
<td>15.6</td>
<td>97.9</td>
<td>6.3</td>
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<td>HV9</td>
<td>Recirculate Exhaust Air Back into Booth During Drying Operations, Building 2225</td>
<td>59 3.8</td>
<td>3.8</td>
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<tr>
<td>HV10</td>
<td>Replace heaters, insulate roof and improve usage of the heat exchange station In Warehouse, Building #2238</td>
<td>185.6 12.06</td>
<td>12.06</td>
<td>98.42</td>
<td>8.2</td>
<td>K</td>
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<tr>
<td>HV11</td>
<td>Replace heaters, insulate roof and improve usage of the heat exchange station In Warehouse, Building #2239</td>
<td>283.5 18.43</td>
<td>18.43</td>
<td>145.5</td>
<td>7.9</td>
<td>K</td>
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<td>HV12</td>
<td>Improve System Efficiency in Tire Repair and Masking Area-Building 2255</td>
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<td>HV13</td>
<td>Place Thermostat Controls Away From Occupants. Improved Control For Air Heaters</td>
<td>105 8.4</td>
<td>8.4</td>
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<td>HV14</td>
<td>Increase Ventilation to Reduce Solvent Fumes in Space-Building 2222</td>
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<td>HV15</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop Building 2225</td>
<td>76.5 4.4</td>
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<td>HV16</td>
<td>Provide Heaters over Doors on South Side- Building 2226</td>
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<td>100</td>
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<td>HV17</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Maintenance Building 2226</td>
<td>120</td>
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<td>7.8</td>
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<td>7</td>
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<td>HV18</td>
<td>Separate the Building Heating System from the Boiler and Connect the Building to District Heating System at Apprentice Shop, Building # 2364</td>
<td>~25%</td>
<td>~25%</td>
<td></td>
<td></td>
<td></td>
<td>&lt; 5 yrs</td>
<td>K</td>
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<td>HV19</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Apprentice Shop, Building # 2363</td>
<td>75</td>
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<td>4.9</td>
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<td>HV20</td>
<td>Replace Warm Air Heaters with Hot Water Radiant Panels in Paint Shop, Building # 2372</td>
<td>190</td>
<td>11.4</td>
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<td>HV21</td>
<td>Have Heating Utility Turn off Heat to Buildings when not Warranted</td>
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<td>HV22</td>
<td>Use Heat from Generator Test for Building Heat, Building 2362</td>
<td>78</td>
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<td>15</td>
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<td>HV23</td>
<td>Provide Door Heater at Door on East Side of Building 2371</td>
<td>36</td>
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<td>2.3</td>
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<td>10.7</td>
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<td>HV24</td>
<td>Provide Better Controls of H&amp;V In Building 2371</td>
<td>365</td>
<td>29.2</td>
<td>600</td>
<td>29.2</td>
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<td>HV25</td>
<td>Insulate Heating System Components-Building 2371</td>
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<td>Provide Temperature Control Of Unit Heaters In Building 2281</td>
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<td>HV27</td>
<td>Improve HVAC System Controls Building 4000</td>
<td>0</td>
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<td>65</td>
<td>65</td>
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<td>HV28</td>
<td>Install Door Heater, Building 4155</td>
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<td>Improve H&amp;V System Controls and Air Movement In Building 4171, Pirmasens</td>
<td>105</td>
<td>8.4</td>
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<td>34.4</td>
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</tr>
<tr>
<td>HV30</td>
<td>Install Economizers, Building 4111, Pirmasens</td>
<td>0</td>
<td>799.2</td>
<td>40</td>
<td>40</td>
<td>90</td>
<td>2.3</td>
<td>P</td>
</tr>
<tr>
<td>HV31</td>
<td>Reduce Hot Water Temperatures—Building 4111 Pirmasens</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>P</td>
</tr>
<tr>
<td>HV32</td>
<td>Install Measurement Equipment, Building 4111</td>
<td>16.5</td>
<td>1.3</td>
<td>812.5</td>
<td>40.6</td>
<td>50</td>
<td>1.2</td>
<td>P</td>
</tr>
<tr>
<td>HV33</td>
<td>Heating system improvement in Commissary at Katterbach Building 5805</td>
<td>-</td>
<td>45.3</td>
<td>3.7</td>
<td>3.7</td>
<td>22</td>
<td>5.9</td>
<td>P</td>
</tr>
<tr>
<td>HV34</td>
<td>Energy Retrofit in Gym-Building 5805</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>HV35</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5801</td>
<td>149</td>
<td>8.94</td>
<td>8.94</td>
<td>59.75</td>
<td>6.7</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>HV36</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5802</td>
<td>90</td>
<td>5.9</td>
<td>5.9</td>
<td>40</td>
<td>6.7</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>HV37</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5508</td>
<td>-</td>
<td>100</td>
<td>6</td>
<td>6</td>
<td>40</td>
<td>6.7</td>
<td>A</td>
</tr>
<tr>
<td>HV38</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5807</td>
<td>-</td>
<td>107</td>
<td>6.42</td>
<td>6.42</td>
<td>50</td>
<td>7.8</td>
<td>A</td>
</tr>
<tr>
<td>HV39</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Katterbach Hangar 5806</td>
<td>-</td>
<td>80</td>
<td>4.8</td>
<td>4.8</td>
<td>62</td>
<td>12.9</td>
<td>A</td>
</tr>
<tr>
<td>HV40</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6500</td>
<td>-</td>
<td>269</td>
<td>16.14</td>
<td>-</td>
<td>16.14</td>
<td>79</td>
<td>A</td>
</tr>
<tr>
<td>HV41</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6501</td>
<td>-</td>
<td>142</td>
<td>8.52</td>
<td>-</td>
<td>8.52</td>
<td>45</td>
<td>A</td>
</tr>
<tr>
<td>HV42</td>
<td>Replace Warm Air Heating With Hot Water Radiant Panels In Illesheim Hangar 6502</td>
<td>-</td>
<td>235</td>
<td>14.1</td>
<td>-</td>
<td>14.1</td>
<td>83</td>
<td>A</td>
</tr>
<tr>
<td>ECM</td>
<td>ECM Description</td>
<td>Electrical Savings</td>
<td>Thermal Savings</td>
<td>Additional Savings ($K/yr)</td>
<td>Total Savings ($K/yr)</td>
<td>Investment ($K)</td>
<td>Simple Payback (yrs)</td>
<td>Location</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------------------------</td>
<td>--------------------</td>
<td>----------------</td>
<td>---------------------------</td>
<td>-----------------------</td>
<td>------------------</td>
<td>----------------------</td>
<td>----------</td>
</tr>
<tr>
<td>HV43⁴⁰</td>
<td>Complex Energy Retrofit at Flight Simulator Building 6658, Illiesheim</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>CEP1</td>
<td>Turn Off District Heating To Buildings In Summer</td>
<td>1019</td>
<td>47.9</td>
<td></td>
<td>47.9</td>
<td>20</td>
<td>0.4</td>
<td>K</td>
</tr>
<tr>
<td>EL1</td>
<td>Switch off Computers When Not In Use — Bldg 2233</td>
<td>36.8</td>
<td>2.9</td>
<td></td>
<td>2.9</td>
<td>0</td>
<td>0</td>
<td>K</td>
</tr>
<tr>
<td>EL2</td>
<td>Switch off Computers When Not In Use Building 4000</td>
<td>24.5</td>
<td>2</td>
<td></td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>P</td>
</tr>
<tr>
<td>WS1</td>
<td>Elementary School: Heating System, Windows, Roof, Lighting, Walls, Solar Shading</td>
<td>17.2</td>
<td>2.5</td>
<td>3073</td>
<td>151.8</td>
<td>154.3</td>
<td>3592</td>
<td>WS</td>
</tr>
<tr>
<td>WS2</td>
<td>Middle School: Windows, Roof, Lighting, Walls, Solar Shading</td>
<td>8.6</td>
<td>1.2</td>
<td>1492</td>
<td>73.7</td>
<td>74.9</td>
<td>1765</td>
<td>WS</td>
</tr>
</tbody>
</table>

Note:
1. This ECM provides a holistic approach to lighting solution which includes reducing the number of lamps, changing the lamps to more energy effective and improve the illumination by treating the floor surfaces to be more reflective as in the Hangar 2, Katterbach. Pay-back in 2-3 yrs
2. Concept BE2a is recommended as more cost effective
3. Concept BE4 is not cost effective
4. HV1 Requires moderate investments resulting in up to 20% thermal energy savings with the payback within one heating season
5. This ECM will result in productivity improvement in summer and winter seasons. Requires further study with support from the shop management
6. Implementation of this ECM doesn’t have economical justification but is strongly recommended for safety and health reason
7. Implementation of this ECM doesn’t have economical justification but is strongly recommended for workers comfort reason
8. This no-cost ECM will reduced heat losses in the system with an immediate pay-back
9. Complex implementation of this ECM will reduce energy consumption and will result in improved thermal comfort, Short payback period.
10. This building has a significant potential for energy savings and improvement in thermal comfort and indoor air quality. Requires a Level II energy audit.

Annotation K refers to ECM at Keiserslautern location, P – Pirmasens, A – Ansbach area and WS – Wiesbaden.
Appendix C: German Standards

This appendix contains explanations and an English version of some current German standards and guidelines concerning energy conservation, requirements to building envelope thermal characteristics and air tightness, heating and ventilation system. This appendix was prepared upon the request from IMA European Region and USACE, Europe District.

1 Thermal protection and power saving in buildings

The minimum requirements imposed to the thermal insulation of components and for restricting the annual heating requirement are defined according to EneG (energy saving law), WäschV (heat insulation ordinance) and DIN 4106 (standards). The standards will provide thermal protection details for planning and performance of common rooms in buildings, which shall be heated to the standard indoor temperatures (≥19°C).

- Requirements for restricting the annual heating requirement as a function of A/V (ratio of the heat transferring enclosing surface A to the enclosed building volume V from A).

Table 1.1: Maximum values of the annual heating requirement depending on the heated building volume or the building active surface $A_H$ as a function of A/V

<table>
<thead>
<tr>
<th>A/V</th>
<th>-</th>
<th>Maximum annual heating requirement</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depending on building volume $V$, $Q_{a1}^{1)}$</td>
<td>Depending on building active surface $A_H$, $Q_{a2}^{2)}$</td>
<td></td>
</tr>
<tr>
<td>in m²</td>
<td>in kWh/(m² a)</td>
<td>in kWh/(m² a)</td>
<td></td>
</tr>
<tr>
<td>&lt;=0,2</td>
<td>17,3</td>
<td>54,0</td>
<td></td>
</tr>
<tr>
<td>0,3</td>
<td>19,0</td>
<td>59,4</td>
<td></td>
</tr>
<tr>
<td>0,4</td>
<td>20,7</td>
<td>64,8</td>
<td></td>
</tr>
<tr>
<td>0,5</td>
<td>22,5</td>
<td>70,2</td>
<td></td>
</tr>
<tr>
<td>0,6</td>
<td>24,2</td>
<td>75,6</td>
<td></td>
</tr>
<tr>
<td>0,7</td>
<td>25,9</td>
<td>81,1</td>
<td></td>
</tr>
<tr>
<td>0,8</td>
<td>27,7</td>
<td>86,5</td>
<td></td>
</tr>
<tr>
<td>0,9</td>
<td>29,4</td>
<td>91,9</td>
<td></td>
</tr>
<tr>
<td>1,0</td>
<td>31,1</td>
<td>97,3</td>
<td></td>
</tr>
<tr>
<td>&gt;=1,05</td>
<td>32,0</td>
<td>100,0</td>
<td></td>
</tr>
</tbody>
</table>

1) $Q_{a1} = Q_a / V$
2) $Q_{a2} = Q_a / A_H$

The values depending on the building active surface (table 1.1, column 3) shall be only used in case of buildings with an unobstructed height of 2.60 m or less.

- Minimum values for the heat flux resistances of non-transparent components
  - Requirements for single-layered or multi-layered massive components

Table 1.2 shows the room limit values required by single components with a total mass depending on the surface of minimum 100 kg/m².
Table 1.2: Minimum values for the heat flux resistances of components

<table>
<thead>
<tr>
<th>Line</th>
<th>Components</th>
<th>Heat flux resistances R in m² K/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Exterior walls; common rooms walls toward basement rooms; passages, open corridors, garages, ground</td>
<td>1.5²</td>
</tr>
<tr>
<td>2</td>
<td>Walls between external used rooms; flat walls</td>
<td>0.05²</td>
</tr>
<tr>
<td>3</td>
<td>Stairwell walls</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>To stairwells with considerably lower indoor temperatures (e.g., indirectly heated stairwell); indoor temperature ( T &lt; T_{W,C} ); stairwell shall be at least without frost</td>
<td>0.25²</td>
</tr>
<tr>
<td>5</td>
<td>Flat walls, ceilings between external wet rooms; ceilings underneath rooms; between insulated conical roofs and walls in adjacent rooms in case of completed attics</td>
<td>0.35²</td>
</tr>
<tr>
<td>6</td>
<td>In general</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Under closure common rooms without basement</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Directly at the ground up to a room depth of 5 m.</td>
<td>0.17²</td>
</tr>
<tr>
<td>9</td>
<td>Ceilings underneath non-completed attics; ceilings underneath ventilated rooms between conical roofs and walls in adjacent rooms in case of completed attics, insulated conical roofs</td>
<td>0.9²</td>
</tr>
<tr>
<td>10</td>
<td>Basement ceiling, ceiling toward closed, unheated corridors and others</td>
<td>1.2²</td>
</tr>
</tbody>
</table>

For buildings with lower indoor temperatures \( T_{W,C} < 15°C \), \( R = 0.25 \text{ m}^2 \text{ K/W} \)

- Increased heat flux resistances because of frosty conditions

Requirements for lightweight and skeleton components

Increased requirements will apply to exterior walls, ceilings underneath non-completed attics and roofs with a total mass depending on the surface of less than 100 kg/m² with a minimum value of the heat flux resistance \( R > 1.75 \text{ m}^2 \text{ K/W} \). In case of the skeleton components, the requirements are only valid for the space between frameworks. In these cases for the total component an average \( R = 1.0 \text{ m}^2 \text{ K/W} \) shall be observed. The same value will apply to the shatter boxes. For the lid of the shatter boxes the value of \( R = 0.35 \text{ m}^2 \text{ K/W} \) shall be observed.

The non-transparent part of the framework space of the window walls and wings, which account for more than 50% of the total framework surface, must fulfill at least the requirements according to table 2. In the case of surface shares of less than 50% the heat flux resistances must be \( R > 1.6 \text{ m}^2 \text{ K/W} \).

- Limitation of the heat flux in case of panel heating system

In case of panel heating system the heat-transfer coefficient of the layer components between the heating area and the ambient air, the ground or the building parts with significantly low indoor temperatures shall not exceed the value of 0.35 W/(m² K).

- Requirement of radiators in front of the windows

By arranging the radiators in front of external window areas, the heat-transfer coefficient of these components shall not exceed the value 1.5 W/(m² K).

- Simplified detection procedure

For small residential buildings up to 2 floors and up to 3 apartments the maximum values of the heat-transfer coefficient \( k \) showed in table 3 shall not be exceeded.

Table 1.3: Requirements to the heat-transfer coefficient for single exterior components of the heat transferring enclosing surface \( A \) in case of smaller residential buildings

<table>
<thead>
<tr>
<th>Line</th>
<th>Component</th>
<th>Max. heat-transfer coefficient ( k_{ext} ) in W/(m² K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Exterior walls</td>
<td>( k_x \leq 0.5 \text{ m}^2 \text{ K/W} )</td>
</tr>
<tr>
<td>2</td>
<td>External windows, window wings and roof windows</td>
<td>( k_{x,reg} \leq 0.7 \text{ m}^2 \text{ K/W} )</td>
</tr>
<tr>
<td>3</td>
<td>Ceilings underneath non-completed attics and roofs (including conical roofs), which isolate rooms upwards and downwards from the ambient air</td>
<td>( k_c \leq 0.25 \text{ m}^2 \text{ K/W} )</td>
</tr>
<tr>
<td>4</td>
<td>Basement ceilings, walls and ceilings towards unheated rooms, ceilings and walls adjacent to the ground</td>
<td>( k_{c,reg} \leq 0.35 \text{ m}^2 \text{ K/W} )</td>
</tr>
</tbody>
</table>

¹ The requirement is fulfilled if the brickwork with a wall thickness of 36.5 cm is executed by building materials with a heat conductivity \( k \leq 0.21 \text{ W/(m K)} \)

² The average equivalent heat-transfer coefficient \( k_{reg} \) shall correspond to a heat-transfer coefficient averaged by all exterior windows and window wings.
2 Heating System

- Construction material classes (acc. to DIN 4102-1)

The construction materials are classified into the construction material classes according to its fire behavior.

Table 2.1: Construction material classes

<table>
<thead>
<tr>
<th>Construction material classes</th>
<th>Building inspection definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Incombustible materials</td>
</tr>
<tr>
<td>A1</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Combustible materials</td>
</tr>
<tr>
<td>B1</td>
<td>Flame resistant materials</td>
</tr>
<tr>
<td>B2</td>
<td>Normal inflammable materials</td>
</tr>
<tr>
<td>B3</td>
<td>Easily inflammable materials</td>
</tr>
</tbody>
</table>

- DIN 2440 Threaded pipes (withdrawn)

This standard will apply for medium-heavy threaded pipes. They shall be appropriated to a nominal pressure 25 for liquidity and a nominal pressure 10 for air and harmless gases.

Dimensions, designation (dimensions in mm)

Rule model

Thread conical (if ordered with thread)

Designation of a medium-heavy threaded pipe nominal diameter 40, seamless zinc-coated (I), producer length.

Table 2.2: Threaded pipes DIN 2440 – DN 40 – seamless zinc-coated B

<table>
<thead>
<tr>
<th>Nominal diameter (DN)</th>
<th>Wall thickness (a)</th>
<th>Outer diameter (d)</th>
<th>Pipe weight (kg/m)</th>
<th>Threads weight (kg/m)</th>
<th>Distance of thread diameter (a) from pipe end (mm)</th>
<th>Weight of threads (kg)</th>
<th>Receptive length (a)</th>
<th>Weight of threads (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.2</td>
<td>10</td>
<td>0.1</td>
<td>0.12</td>
<td>4.2</td>
<td>0.02</td>
<td>260</td>
<td>0.06</td>
</tr>
<tr>
<td>15</td>
<td>0.2</td>
<td>15</td>
<td>0.15</td>
<td>0.15</td>
<td>5.5</td>
<td>0.03</td>
<td>315</td>
<td>0.09</td>
</tr>
<tr>
<td>20</td>
<td>0.3</td>
<td>20</td>
<td>0.16</td>
<td>0.18</td>
<td>6.8</td>
<td>0.04</td>
<td>370</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Depending on an average length 1.5 m.
Type: seamless or welded

Mode of supply: In factory lengths without thread and without bushing. In case of another mode of supply, the designation shall be completed as follows:
In case of supply with conical thread on both ends: with thread
In case of supply with conical thread on both ends and with a screwable bushing: with bushing

Surface treatment

The pipes will be provided in following types according to the respective order:

Table 2.3

<table>
<thead>
<tr>
<th>Surface</th>
<th>abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td></td>
</tr>
<tr>
<td>Black, appropriate for zinc coating</td>
<td>A</td>
</tr>
<tr>
<td>Coated with zinc</td>
<td>B</td>
</tr>
<tr>
<td>Non metallic protective coating</td>
<td>Outside</td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
<tr>
<td>by arrangement</td>
<td></td>
</tr>
</tbody>
</table>

- Seamless steel pipes acc. to DN 50 (DIN EN 10216 part 1)

This part of the EN 10216 will contain the technical supply conditions for two qualities, TR1 and TR2, seamless pipe with round profile made out of soft steel with fixed room temperature properties.

This standard will contain the ordering details, the manufacturing process (pipe manufacturing and supply condition), requirements (chemical composition, mechanical properties, and measures, masses depending on the length and boundary deviations), test procedures etc.

- DIN 2441 Threaded pipes (withdrawn)

This standard will apply for heavy threaded pipes. They shall be appropriated to a nominal pressure 25 for liquidity and a nominal pressure 10 for air and harmless gases.

Dimensions, designation (dimensions in mm)

Rule model

Thread conical (if ordered with thread)

Designation of a medium-heavy threaded pipe nominal diameter 40, seamless zinc-coated (B), manufacturer's length:
Table 2.4 Threaded pipes DIN 2441 – DN 40 – seamless B

<table>
<thead>
<tr>
<th>DN</th>
<th>Normal diameter of the thread (mm)</th>
<th>Normal diameter of the pipe (mm)</th>
<th>Weight</th>
<th>Threads (mm)</th>
<th>Taper angle</th>
<th>Standard thread length</th>
<th>Distance of the threads from pipe end</th>
<th>Outside diameter (mm)</th>
<th>Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1.8</td>
<td>16.2</td>
<td>0.943</td>
<td>0.696</td>
<td>9.778</td>
<td>28</td>
<td>7.4</td>
<td>4.0</td>
<td>3.1</td>
</tr>
<tr>
<td>6</td>
<td>2.5</td>
<td>20.5</td>
<td>1.280</td>
<td>0.972</td>
<td>13.577</td>
<td>38</td>
<td>11.6</td>
<td>7.9</td>
<td>6.4</td>
</tr>
<tr>
<td>10</td>
<td>3.5</td>
<td>31.5</td>
<td>1.902</td>
<td>1.329</td>
<td>18.942</td>
<td>49</td>
<td>15.6</td>
<td>13.1</td>
<td>9.1</td>
</tr>
<tr>
<td>14</td>
<td>5.2</td>
<td>43.7</td>
<td>2.57</td>
<td>1.810</td>
<td>23.641</td>
<td>59</td>
<td>19.6</td>
<td>18.9</td>
<td>12.6</td>
</tr>
<tr>
<td>20</td>
<td>7.0</td>
<td>55.9</td>
<td>3.84</td>
<td>2.387</td>
<td>31.548</td>
<td>79</td>
<td>23.6</td>
<td>23.8</td>
<td>16.5</td>
</tr>
<tr>
<td>25</td>
<td>9.3</td>
<td>67.2</td>
<td>5.64</td>
<td>3.184</td>
<td>34.610</td>
<td>99</td>
<td>27.6</td>
<td>28.7</td>
<td>20.3</td>
</tr>
<tr>
<td>32</td>
<td>11.9</td>
<td>78.5</td>
<td>7.64</td>
<td>4.137</td>
<td>41.105</td>
<td>119</td>
<td>31.5</td>
<td>33.4</td>
<td>24.1</td>
</tr>
<tr>
<td>40</td>
<td>15.5</td>
<td>90.9</td>
<td>9.64</td>
<td>4.947</td>
<td>47.605</td>
<td>139</td>
<td>35.4</td>
<td>38.2</td>
<td>28.9</td>
</tr>
<tr>
<td>50</td>
<td>19.1</td>
<td>103.3</td>
<td>11.64</td>
<td>5.847</td>
<td>54.110</td>
<td>169</td>
<td>39.3</td>
<td>43.1</td>
<td>33.0</td>
</tr>
<tr>
<td>60</td>
<td>22.8</td>
<td>115.7</td>
<td>13.64</td>
<td>6.847</td>
<td>60.610</td>
<td>189</td>
<td>43.2</td>
<td>47.2</td>
<td>37.9</td>
</tr>
<tr>
<td>80</td>
<td>28.0</td>
<td>138.1</td>
<td>17.64</td>
<td>8.847</td>
<td>72.810</td>
<td>229</td>
<td>51.2</td>
<td>51.2</td>
<td>42.0</td>
</tr>
</tbody>
</table>

Type: Seamless or welded

Mode of supply: In manufacturer’s lengths without thread and without bushing.
In case of another mode of supply, the designation shall be completed as follows:
In case of supply with conical thread on both ends: with thread
In case of supply with conical thread on both ends and with a screwable bushing: with bushing

Surface treatment

The pipes will be provided in following types according to the respective order:

Table 2.5

<table>
<thead>
<tr>
<th>Surface</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>A</td>
</tr>
<tr>
<td>Black, appropriate for zinc coating</td>
<td>B</td>
</tr>
<tr>
<td>Coated with zinc</td>
<td>C</td>
</tr>
<tr>
<td>Non metallic protective coating</td>
<td>D</td>
</tr>
</tbody>
</table>

DIN EN 10255: Replacement for DIN 2440 and DIN 2441 !

This document shall define the requirements on round pipes made out of mild steel that are appropriate to welding and threading and provides a set of options for the pipe quality and for the coatings. This document shall apply to pipes with a nominal outer diameter from 10.2 mm to 165.1 mm (thread size 1/8 to 6) for two series, middle and heavy line and to 3 other pipe types with fixed wall thickness.

This standard will contain the ordering designation, the manufacturing process (pipe manufacturing and supply conditions), requirements (chemical composition, mechanical properties, and measures, masses depending on the length and boundary deviations), test procedures etc.
• DIN 2394 (withdrawn)

DIN EN 10305 part 3: Replacement for DIN 2394

This part of the EN 10305 will contain the technical supply conditions for welded rolled steel precision pipes with round profiles.

Pipes according to this part of EN 10305 are characterized by precisely defined boundary deviations and a fixed surface finish. Typical applications areas are the vehicle construction, the furniture industry and the general engineering.

This standard will contain the ordering designation, the manufacturing process (pipe manufacturing and supply condition), requirements (chemical composition, mechanical properties, and measures, masses depending on the length and boundary deviations), test procedures etc.

• Selection of Radiators
  - Dimensioning VDI 5230: (to enclose)
  - Heat capacity tested (DIN EN 1442): (to enclose)

• Selection of thermostatic valves and thermostatic heads: (to enclose)
• The heating system shall be balanced acc. to DIN 18 380. (Note: the standard was completely revised)

• DIN 4109 (DIN 4109 supplementary sheet 2) (Sound insulation)

The details for the sewage pipe will apply analogously as for the piping of the heating system.

The flow processes occurring at the sewage discharge, especially at the sewage connections and in case of changes of direction, will activate the sewage pipe to mechanical vibrations, which will be transmitted themselves at the walls with the fixed pipes.

The following means for noise reduction will be available (apart from constructional means):
  - The sewage pipes shall not be led over at walls in rooms requiring a high sound insulation
  - The pipe routing will require a structure-borne sound insulation
  - Prevention of drastic changes of direction

• DIN 3567

Pipe clamp for nominal diameter 20 to 500 (measures in mm)

Designation of a pipe clamp form B with a clear diameter d₁: 82 mm.

Pipe clamp B 89 DIN 3567
Appropriate nuts shall be commanded particularly.

<table>
<thead>
<tr>
<th>d (mm)</th>
<th>Applicable in case of nominal diameter</th>
<th>Pipe clamp</th>
<th>Fast steel acc. to DIN 1017</th>
<th>Appropriate hexagon bolts acc. to DIN 601</th>
<th>Weight (7.85 kg/dm³) kg/100 piece form</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>A</td>
<td>0.62</td>
<td>0.66</td>
<td>M10x30Mu</td>
<td>21.47, 31.79</td>
</tr>
<tr>
<td>27</td>
<td>B</td>
<td>0.72</td>
<td>0.66</td>
<td>M10x30Mu</td>
<td>23.37, 33.95</td>
</tr>
<tr>
<td>30</td>
<td>C</td>
<td>0.82</td>
<td>0.82</td>
<td>M10x30Mu</td>
<td>24.79, 35.15</td>
</tr>
<tr>
<td>34</td>
<td>D</td>
<td>0.92</td>
<td>0.82</td>
<td>M10x30Mu</td>
<td>26.12, 36.57</td>
</tr>
<tr>
<td>38</td>
<td>E</td>
<td>1.02</td>
<td>0.82</td>
<td>M10x30Mu</td>
<td>27.57, 38.09</td>
</tr>
<tr>
<td>43</td>
<td>F</td>
<td>1.12</td>
<td>0.84</td>
<td>M10x30Mu</td>
<td>28.81, 39.37</td>
</tr>
<tr>
<td>45</td>
<td>G</td>
<td>1.14</td>
<td>0.84</td>
<td>M10x30Mu</td>
<td>30.37, 40.72</td>
</tr>
<tr>
<td>50</td>
<td>H</td>
<td>1.22</td>
<td>0.88</td>
<td>M10x30Mu</td>
<td>58.10, 79.55</td>
</tr>
<tr>
<td>54</td>
<td>I</td>
<td>1.30</td>
<td>0.88</td>
<td>M10x30Mu</td>
<td>58.20, 79.89</td>
</tr>
<tr>
<td>57</td>
<td>J</td>
<td>1.38</td>
<td>0.88</td>
<td>M10x30Mu</td>
<td>66.60, 85.96</td>
</tr>
<tr>
<td>59</td>
<td>K</td>
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<td>0.88</td>
<td>M10x30Mu</td>
<td>75.30, 95.09</td>
</tr>
<tr>
<td>61</td>
<td>L</td>
<td>1.46</td>
<td>0.88</td>
<td>M10x30Mu</td>
<td>86.90, 105.09</td>
</tr>
<tr>
<td>64</td>
<td>M</td>
<td>1.50</td>
<td>0.88</td>
<td>M10x30Mu</td>
<td>104.20, 123.09</td>
</tr>
<tr>
<td>66</td>
<td>N</td>
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<td>M10x30Mu</td>
<td>122.20, 140.09</td>
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<tr>
<td>68</td>
<td>O</td>
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<tr>
<td>70</td>
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<td>159.10, 178.00</td>
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<tr>
<td>72</td>
<td>Q</td>
<td>1.62</td>
<td>0.88</td>
<td>M10x30Mu</td>
<td>163.40, 182.00</td>
</tr>
<tr>
<td>75</td>
<td>R</td>
<td>1.66</td>
<td>0.88</td>
<td>M10x30Mu</td>
<td>183.10, 202.00</td>
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<tr>
<td>90</td>
<td>S</td>
<td>1.70</td>
<td>0.88</td>
<td>M10x30Mu</td>
<td>199.00, 218.00</td>
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<tr>
<td>100</td>
<td>T</td>
<td>1.75</td>
<td>0.88</td>
<td>M10x30Mu</td>
<td>208.10, 227.00</td>
</tr>
<tr>
<td>110</td>
<td>U</td>
<td>1.78</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>239.40, 258.00</td>
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<tr>
<td>120</td>
<td>V</td>
<td>1.80</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>242.00, 261.00</td>
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<tr>
<td>130</td>
<td>W</td>
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<td>0.88</td>
<td>M10x45Mu</td>
<td>260.00, 279.00</td>
</tr>
<tr>
<td>140</td>
<td>X</td>
<td>1.84</td>
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<td>M10x45Mu</td>
<td>264.40, 283.00</td>
</tr>
<tr>
<td>150</td>
<td>Y</td>
<td>1.86</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>284.40, 303.00</td>
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<tr>
<td>160</td>
<td>Z</td>
<td>1.88</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>301.00, 320.00</td>
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<tr>
<td>170</td>
<td>[1]</td>
<td>1.90</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>320.00, 339.00</td>
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<tr>
<td>180</td>
<td>[2]</td>
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<td>0.88</td>
<td>M10x45Mu</td>
<td>339.00, 358.00</td>
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<tr>
<td>190</td>
<td>[3]</td>
<td>1.94</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>358.00, 377.00</td>
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<td>377.00, 396.00</td>
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<td>0.88</td>
<td>M10x45Mu</td>
<td>396.00, 415.00</td>
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<td>220</td>
<td>[6]</td>
<td>2.00</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>415.00, 434.00</td>
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<td>230</td>
<td>[7]</td>
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<td>0.88</td>
<td>M10x45Mu</td>
<td>434.00, 453.00</td>
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<tr>
<td>240</td>
<td>[8]</td>
<td>2.04</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>453.00, 472.00</td>
</tr>
<tr>
<td>250</td>
<td>[9]</td>
<td>2.06</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>472.00, 491.00</td>
</tr>
<tr>
<td>260</td>
<td>[10]</td>
<td>2.08</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>491.00, 510.00</td>
</tr>
<tr>
<td>270</td>
<td>[11]</td>
<td>2.10</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>510.00, 529.00</td>
</tr>
<tr>
<td>280</td>
<td>[12]</td>
<td>2.12</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>529.00, 548.00</td>
</tr>
<tr>
<td>290</td>
<td>[13]</td>
<td>2.14</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>548.00, 567.00</td>
</tr>
<tr>
<td>300</td>
<td>[14]</td>
<td>2.15</td>
<td>0.88</td>
<td>M10x45Mu</td>
<td>567.00, 586.00</td>
</tr>
</tbody>
</table>

1) Approximately identically to the outer diameter of the appropriate pipe.
2) The indicated measures b shall be minimum dimensions. Dimensions varying from the table shall be indicated by ordering; the designation is for a pipe clamp form B with a clear diameter d₁ = 89 mm and e.g. b = 60mm. pipe clamp B 89 x 60 DIN 3667

Sizes in brackets shall be avoided.
• EnEV (energy saving ordinance)

EnEV annex 5. Requirements for restricting the heat output of the heating and hot water pipes and fittings.

The heat output of the heating and hot water pipes and fittings shall be limited by thermal insulation according to table 2.6.

Table 2.6: Thermal insulation of heating and hot water pipes and fittings

<table>
<thead>
<tr>
<th>Line</th>
<th>Type of pipes/fitting</th>
<th>Min. insulation layer thickness depending on the thermal conductivity of 0.035 W/(m K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Internal diameter up to 22 mm</td>
<td>20 mm</td>
</tr>
<tr>
<td>2</td>
<td>Internal diameter over 22 mm - 35 mm</td>
<td>30 mm</td>
</tr>
<tr>
<td>3</td>
<td>Internal diameter over 35 mm up to 100 mm</td>
<td>Equal internal diameter</td>
</tr>
<tr>
<td>4</td>
<td>Internal diameter over 100 mm</td>
<td>60 mm</td>
</tr>
<tr>
<td>5</td>
<td>Pipes and fittings acc. to the lines 1 up to 4 at wall and ceiling penetrations, at pipes cross, at pipes joints, at central piping distributions</td>
<td>1/2 of the requirements acc. to lines 1 up to 4</td>
</tr>
<tr>
<td>6</td>
<td>Pipes of central heating plants acc. to lines 1 up to 4, that should be run acc. to the commencement of the ordinance in components between heated rooms of different users</td>
<td>1/2 of the requirements acc. to the lines 1 up to 4</td>
</tr>
<tr>
<td>7</td>
<td>Pipes acc. to the line 6 in the floor construction</td>
<td>8 mm</td>
</tr>
</tbody>
</table>

If pipes of central heating plants acc. to the lines 1 up to 4 in heated rooms or in components between heated rooms of an user exist and if its heat output can be influenced by led open shut-offs, no requirements on the min. insulation layer thickness will be requested. That shall apply as well to hot water piping in apartments up to an internal diameter of 22 mm, which are not included in the circulation and not equipped with an electrical tracer heating.

In case of materials with a thermal conductivity different from 0,035 W/(m K), the min. insulation layer thickness shall be converted analogously. For the conversion and the thermal conductivity, the arithmetic techniques and the arithmetic values in the rules of techniques shall be used.

In case of the heating and hot water pipes the min. insulation layer thicknesses acc. to table 1 should be only allowed to be reduced if an equivalent limitation of heat output will be secured in case of other pipe insulation structures and with consideration of the insulation effect of the piping walls.
3 Ventilation System

- DIN 24145 and DIN 24146: withdrawn
- DIN 1949: nothing to do with “wall thickness”
- DIN 18017

- Individual exhaust ventilation systems with own exhaust air lines: These exhaust ventilation systems are equipped per apartment with one exhaust line in the outside (fig. 3-1)

![Fig. 3-1 Individual exhaust ventilation systems with own exhaust air lines.](image)

- Individual exhaust ventilation systems with collective exhaust air lines: These exhaust ventilation systems are equipped for many apartments with an collective exhaust line (principal line), charging the exhaust air under overpressure (fig.3-2)

![Fig. 3-2 Individual exhaust ventilation systems with collective exhaust air line (principal line).](image)
- DIN 4109
  The VDI 2061 shall be considered for design and realization of the measures for sound reduction (VDI 2061-1 and -2 enclose)
- LBO-(BW) Landesbauordnung für Baden-Württemberg (building code of Baden-Württemberg)

§ 31 Ventilation systems, installation shafts and ducts

(1) Ventilation systems shall be fail-safe and fireproof. They should not affect the correct operating of the fireplaces. They must be placed and manufactured in the way that they cannot transport odors and dust to other rooms. The sound conduction in external rooms must be sufficiently insulated.

(2) For installation shafts and ducts shall apply analogously paragraph 1.
  - NFPA: English version
  - UFC 3-600-01: English version

Requirements to the air tightness of building envelope components

- DIN 4108-2
  The joint permeability coefficient concerning the connection joints of the building components resulting from measurements must be less than 0,1 m³/m²h (daPa⁻¹).
  In case of windows and window doors the requirements acc. to DIN 18055 shall be applied. In case of outer doors the joint permeability coefficient must be a <=2,0 m³/m²h (daPa⁻¹).

- DIN 4108-7
  If measurements of the air tightness of buildings or building components are made, the measured air volume flow considering the pressure difference between inside and outside of 50 Pa
  - in case of buildings without HVAC systems:
    - depending on the air volume should not exceed 3 h⁻¹
    - depending on the net base-area should not exceed 7,8 m³/(m² h)
  - in case of buildings with HVAC system (also exhaust air installation):
    - depending on the air volume should not exceed 1,5 h⁻¹
    - depending on the net base-area should not exceed 3,9 m³/(m² h)

  The requirements depending on the volume shall be generally applied. In case of buildings or building components with the clear height between floors is 2,6 m or less, the requirement values depending on the net base-area can be used alternatively.

- WSchV
  Table: joint permeability coefficients for outside window and window doors as well as for outer doors (requirement categories acc. to DIN 18055)

<table>
<thead>
<tr>
<th>Number of floors</th>
<th>Joint permeability coefficient a in m³/m²h (daPa⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>1 Buildings up to 2 complete floors</td>
<td>2.0</td>
</tr>
<tr>
<td>2 Buildings with more than 2 complete floors</td>
<td>-</td>
</tr>
</tbody>
</table>

1) requirement categories
A: building height up to 8 m
B: building height up to 20 m
C: building height up to 100 m
### VDI-RICHTLINIEN

**VEREIN DEUTSCHER INGENIEURE**  
Auslegung von freien Raumheizflächen: Grundlagen  
Auslegung von Raumheizkörpern  
Designing free heating surfaces: Fundamentals  
Designing of heating appliances

**VDI 6030**  
Blatt 1 / Part 1  
Ausg. deutsch/englisch  
Iss. German/English

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**Inhalt**  
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<td>5 Grundlagen für die Auslegung</td>
<td>5 Fundamentals of designing</td>
</tr>
</tbody>
</table>

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*Die deutsche Version dieser Richtlinie ist verbindlich.*  
*No guarantee can be given with respect to the English translation. The German version of this guideline shall be taken as authoritative.*

---

VDI-Gesellschaft Technische Gebäudeausrüstung (TGA)  
VDI/DIN Handbuch Wärme- /Heiztechnik
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Preliminary note

This VDI-guideline is intended for use in the design of free heating surfaces for water-based heating systems. The guideline specifies rules for the determination of the visible-surface dimensions, the inlet and outlet water temperatures, the water flow rate, and the standard thermal output of the selected free heating surface.

For the architect, this VDI-guideline serves to illustrate the interaction between the room design and the requirements to be met by the free heating surfaces. For the planner and heating-system manufacturer, it establishes a basis for tailoring free heating surfaces in a room to the building concept, and to the requirements arising from the use of the room. It is, therefore, also an aid to the orderer, in specifying his ideas and desires to sufficient detail.

This VDI-guideline, therefore, aims at matching the scope of designing with the orderer’s requirements. This means that in the process of designing, several functions of the free heating surfaces are specified: In addition to covering the heating load, they also serve to reduce or compensate possible deficits in comfort by heating up exteriors surfaces, insulating the room to be heated, or by compensating radiation deficits due to colder surfaces, and by eliminating downdrafts. In principle, these functions can be verified by measurements. Further functions may include the fulfillment of aesthetic requirements and the additional use of free heating surfaces for the purpose of, e.g., hanging towels or clothes, partitioning a room, etc.

In consequence, by defining clear functional requirements (according to type and scope), this VDI-guideline also provides a basis for comparing design variants. In order to emphasize the system-dependent differences between design variants for free heating surfaces, the effects of heating-surface functions which serve to compensate deficits in comfort are described in terms of the requirements zone achievable in the room, and the class of requirements. In this guideline, the provisions of DIN pr EN 12 828 for the dimensioning of heating surfaces are covered in greater detail, thus offering guidance on achieving compliance with the requirements of this standard in practical applications.

VDI wishes to express its thanks to all those experts who contributed, by way of honorary work, to drafting this guideline.

---

1) Zum Zwecke der Auslegung freier Raumheizflächen eingeführte Definition
1 Geltungsbereich und Zweck


Die Auslegung beinhaltet

- in einem ersten Schritt die Festlegung des Anbringungsortes des Raumheizkörpers, die Typauswahl für den vorliegenden Zweck, die Festlegung der Anreicherungsmessung und die Berechnung der mittleren Heizflächenbeherdungstemperatur,
- in einem zweiten Schritt die Berechnung der Vor- und Rücklauftemperaturen, des Wassersstroms und der Norm-Wärmeleistung des Raumheizkörpers unter Beachtung der Normtemperatur und einer vorgegebenen Aufheizreserve,
- in einem dritten Schritt die Auswahl des erforderlichen Heizkörpermodells.

1 Scope and purpose

This guideline applies to the designing of free heating surfaces for water-based heating systems in residential, office and other buildings where day rooms are used similarly. This guideline aims at establishing a set of requirements including comfort and efficient use of energy, which means exceeding the simple aim of just covering the required design heating load. Three different classes of requirements allow determining and limiting, the scope of functions of the free heating surface to be designed, depending on the application. This serves to avoid that the highest class can be claimed as a matter of principle. The restriction to free heating surfaces is not intended to indicate that other room heating systems do not achieve the classes of requirements described here.

The effect of forced ventilation by means of fans on the air flow in a room is not covered in this guideline. Designing includes the following steps:

- firstly, the determination of the location where the free heating surface is to be installed, selection of the appropriate type, dimensioning of the visible surfaces, and the calculation of the mean heating-surface excess temperature,
- secondly, the calculation of the inlet and outlet water temperatures, water flow rate, and standard thermal output of the heating surface, taking into account the design heating load and a specified heating-up reserve,
- thirdly, the selection of the appropriate heating-appliance model.
2 Zugehörige Vorschriften, Normen und Richtlinien

<table>
<thead>
<tr>
<th>Vorschriften</th>
<th>Regulations</th>
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<tbody>
<tr>
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<td>WärmeschutzV</td>
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<table>
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Erstes Feld vorbehalten © Verein Deutscher Ingenieure, Düsseldorf 2002

\[ t_r \] Bezugslufttemperatur °C
\[ t_{m} \] mittlere Wassertemperatur °C
\[ U_{w} \] Wärmedurchgangskoeffizient W/(m²K)
\[ U_{U} \] Wärmedurchgangskoeffizient der Umfassungsfläche W/(m²K)
\[ \sigma_{out} \] Spreizung zwischen Vor- und Rücklauf-Wassertemperatur K
\[ \phi \] Wärmeleistung W
\[ \phi_{eff} \] Auslegungswärmereaktionskoeffizient des Heizkörpers
\[ \phi_{l} \] bezogene Wärmeleistung des HK's je m² Baulänge W/m
\[ \phi_{HR} \] Aufheizreserve nach DIN pr EN 12 831 W
\[ \phi_{HRU} \] Aufheizreserve, durch Betriebserwärmung erreichbar W

\[ \phi_{l} \] Normal-Wärmeleistung W
\[ \phi_{l} \] Wärmeübergangskoeffizient W/(m²K)
\[ \phi_{l} \] Temperatur in unbeheizten Räumen °C

\[ \phi_{A} \] Auslegungstemperatur °C
\[ \phi_{1} \] Verlaufstemperatur K
\[ \phi_{2} \] Rückläufertemperatur K
\[ \phi_{3} \] Wasserzubringer K
\[ \phi_{4} \] Normal-Verlaufstemperatur K
\[ \phi_{5} \] Norm-Rückläufertemperatur K
\[ \phi_{6} \] Überwärme der Heizfläche K
\[ \phi_{U} \] Untertemperatur der kalten Umfassungsfläche K

\[ \rho \] Einstrahlnzahl –

**Begriffe**

*Freie Raumheizflächen*


*Raumheizkörper*

Raumheizkörper sind freie Raumheizflächen, die überwiegend vor einer seitlichen Umfassungsfläche, gelegentlich in einem Bodeneinschub (als Unterflur-...

**Terms and definitions**

*Free heating surfaces*

Free heating surfaces are installed in front of, above, or below, an enclosing surface of the room to be heated without being in contact with that enclosing surface except by means of the fixtures. Examples are heating appliances and ceiling-mounted radiant panels.

*Heating appliances*

Heating appliances are free heating surfaces which are mostly installed in front of a lateral enclosing surface, occasionally in a shaft in the floor (as underfloor...
konvektiver) oder frei im Raum (als Raumstrahler o.A.), aber verteilte, immer im unteren Raumbereich angeordnet sind, kurz auch Heizkörper.

Isotherme Umgebung
Alle Umfassungsschichten eines Raumes und die Luft haben überall die gleiche Auslegungs-Imentemperatur (siehe Abschnitt 4.2.2).

„Kalte“ Umfassungsschichten
Umfassungsschichten von Räumen, die kälter sind als eine Fläche mit Auslegungs-Imentemperatur. Für die Auslegung (Abschnitt 6) werden nur „kalte“ Umfassungsschichten herangezogen, deren Oberflächentemperaturen 4 K kälter sind als die Auslegungs-Imentemperatur und eine Mindestdicke von 0,5 m² (Rohbaufläche) überschreiten.

Funktionen
Eigenschaften einer Anlage, die eine Wirkung im Sinne der Anforderung haben.

Kritische Fugendurchlässigkeit
Die Fugendurchlässigkeit wird nach DIN EN 12 207 beschrieben durch eine Referenzdurchlässigkeit für 1 m Fugendicke bei einem Prüfdruck von 100 Pa. Als kritischer Wert im Sinne dieser Richtlinie wird die obere Grenze der Klasse 2 mit 6,75 m²/h/² festgelegt, d.h. bei den Klassen 1 und 0 ist ein Behaglichkeitsdefizit zu vermuten.

Unterbedeutung
Die Differenz zwischen einer mittleren Oberflächentemperatur und der Auslegungs-Imentemperatur.

Betriebsheizfläche
Die Raumeinheizfläche, die bei üblicher Heizung ständig in Betrieb ist.

Zusatzheizfläche
Die Raumeinheizfläche, die zusätzlich zur Betriebsheizfläche bei Aufheizzuständen in Betrieb genommen wird.

Norm-Wasserdurchmesser
Der Wasserdurchmesser unter Norm-Prüfbedingungen.

Heizkörpermodell
Heizkörper einer bestimmten Höhe, Länge und Tiefe innerhalb einer Modellreihe (gemäß DIN EN 442: Heizkörper ähnlicher Bauart, deren Querschnitt gleich bleibt, während Höhe oder Länge sich ändern oder bei denen nur ein charakteristisches Maß der trockenen Heizfläche einer systematischen Änderung

Isotherme environment
At any point in a room, all its enclosing surfaces and the air have the same design indoor temperature (see Section 4.2.2).

“Cold” enclosing surfaces
Those enclosing surfaces of a room which are cooler than a surface at design indoor temperature. Only those “cold” enclosing surfaces are taken into account for designing (see Section 6), whose surface temperature lies 4 K below the design indoor temperature and whose area is at least 0.5 m² (dimensions in unfinished state).

Functions
Those characteristics of a system that have a bearing on its compliance with requirements.

Critical joint permeability
As per DIN EN 12 207, joint permeability is described in terms of a reference air permeability for a joint length of 1 m and a test pressure of 100 Pa. For the purposes of this guideline, the critical value has been set to equal the upper limit of class 2, i.e. 6.75 m²/h/², which means that a deficit in comfort must be assumed for classes 0 and 1.

Under temperature
The difference between a mean surface temperature and the design indoor temperature.

Operating heating area
Heating area which is permanently in operation during normal heating.

Additional heating surface
Heating surface which, for heating up, is used in addition to the normal-duty heating surface.

Standard water flow rate
Water flow rate under standardized test conditions.

Heating-appliance model
Heating appliance within a series of models, featuring a specific height, length and width. (According to DIN EN 442, a series of models comprises heating appliances of similar design, whose cross section remains the same whereas height and length may change, or where only one characteristic dimension
4 Definition und Zusammenstellung der Anforderungen

4.1 Pflichtenheft

Im Pflichtenheft werden die Anforderungen des Auftragnehmers an die Heizanlage aufgelistet. Insbesondere müssen Anforderungen, die von den Empfehlungen einschlägiger technischer Regeln abweichen, aufgenommen werden. Mit dem Pflichtenheft können später die Vollständigkeit und Erfüllung der Pflichtenhefterfordernisse überprüft und die Planungsvarianten (Angebote) verglichen werden.

Das Pflichtenheft ist Bestandteil des Raumbuches und muss mindestens folgende Angaben enthalten:

Auslegungsvorgaben:

- Auslegungs-Innentemperatur $\theta_{A}$ nach Abschnitt 4.2.2
- Anforderungszone nach Abschnitt 4.2.4
- Anforderungsstufe nach Abschnitt 4.2.5
- Aufheizreserve nach Abschnitt 4.2.6 und 5.2.9

Weitere Vorgaben:

- Zusatznutzen nach Abschnitt 4.2.7
- maximale Außentemperatur $\theta_{E,\text{max}}$ nach VDI 2067 Blatt 20 (optional)

Im Anhang A ist ein Beispiel-Pflichtenheft vorgegeben.

4.2 Auslegungsvorgaben

4.2.1 Norm-Innentemperatur

Die Norm-Innentemperatur $\theta_{A}$ eines Raumes ist eine „empfundene Temperatur“ (operative Temperatur), die sowohl die Lufttemperatur als auch die mittlere Umfassungsflächentemperatur (richtungsunabhängig) berücksichtigt (DIN pr EN 12 831, DIN 4701-1). Sie ist eine rechnerische Größe (DIN 4701-3).

4.2.2 Auslegungs-Innentemperatur

Die Auslegung-Innentemperatur $\theta_{A,\text{a}}$ ist die Norm-Innentemperatur, die für den Auslegungsfall in ihrem Wert festgelegt wird. Vorschläge über ihren Wert für Räume unterschiedlicher Nutzung enthält DIN pr EN 12 831 bzw. DIN 4701-2. Diese können jedoch nach Vorgabe durch den Auftraggeber davon abweichen (Pflichtenheft).

4.1 Target specification

The target specification lists the orderer's requirements to be met by the heating system. It is of particular importance that these requirements which deviate from recommendations given in the relevant technical rules be included. Later on, the target specification will allow to check the heating system for completeness and functional compliance, and to compare planning variants (tendens).

The target specification for the heating system is part of the specification of the rooms. It shall at least contain the following information:

Design specifications:

- Design indoor temperature, $\theta_{A}$, as per Section 4.2.2
- Requirements zone as per Section 4.2.4
- Class of requirements as per Section 4.2.5
- Heating-up reserve as per Sections 4.2.6 and 5.2.9

Further specifications:

- Additional use as per Section 4.2.7
- Maximum effort number, $\theta_{E,\text{max}}$, as per VDI 2067 Part 20 (optional)

Annex A shows an example of a target specification.

4.2 Design specifications

4.2.1 Standard indoor temperature

The standard indoor temperature, $\theta_{A}$, of a room is a "subjective temperature" (operative temperature) taking into account both the air temperature and the mean temperature of the enclosing surfaces (non-directional) (DIN pr EN 12 831, DIN 4701-1). It is a calculated quantity (DIN 4701-3).

4.2.2 Design indoor temperature

The design indoor temperature, $\theta_{A,\text{a}}$, is the standard indoor temperature specified for the particular room for which the heating system is to be designed. Recommended values for rooms with different types of use are given in DIN pr EN 12831 and DIN 4701-2. Different values may, however, be used if so specified by the orderer (target specification).
4.2.3 Behaglichkeitsdefizite

Behaglichkeitsdefizite werden hervorgerufen durch:
• "Kalte" Umfassungsflächen
• Luftströmungen in Folge der Fugendurchlässigkeit (kritische Fugendurchlässigkeit) oder an Zuluftstellen (auch für Verbrennungsluft) in den Raumumfassungsfären.


4.2.3 Deficits in comfort

Deficits in comfort are caused by:
• "cold" enclosing surfaces, and
• air flows due to joint permeability (critical joint permeability) or near air inlets (also for combustion air) in the surfaces enclosing the room.

These deficits are considered as differences with respect to an isothermal environment at design indoor temperature, which is undisturbed by air flows. Therefore, by definition, such deficits can only occur outside the requirements zone in a room. Radiation deficit and downdraft are deficits in comfort which are due to the under temperature of “cold” enclosing surfaces.

1) Zum Zwecke der Auslegung bei Raumumfassungsfären eingeführte Definition

1) This definition has been introduced for the purposes of designing free heating surfaces.

Bild 1. Grenzflächen der max. Anforderungszone
Fig. 1. Boundary surfaces of the maximum requirements zone
(Bsp: Raum mit einer "Kalten" Umfassungsfäche)

(example of a room with one "cold" enclosing surface)
4.2.4 Anforderungszonen


Die durch den Auftraggeber vorgegebene Anforderungszone wird nur durch horizontale und vertikale Flächen begrenzt, also durch Abstände von den Umfassungsflächen bzw. durch Raumhöhen. Sie ist in der Regel kleiner als die maximale Anforderungszone (Bild 1). Der Mindestabstand von der „kalten“ Umfassungsfläche beträgt 1 m, der Mindestabstand zu allen anderen senkrechten Umfassungsflächen beträgt 0,3 m; die Höhe der Anforderungszone ist maximal 2 m. Räume mit mehreren Fußbodenebenen (versetzte Bauweise, mehrere Geschosse) sind getrocknet zu betrachten und bedingen mehrere Anforderungszonen.


4.2.5 Anforderungstufe

Für die gewählte Anforderungszone lässt sich die gewünschte Anforderungstufe durch unterschiedlich umfangreiche Beseitigung der Behaglichkeitsdefizite festlegen. Dabei sind drei Anforderungstufen ausreichend.
Stufe 3: Vollständige Beseitigung der Behaglichkeitsdefizite⁴

Die dritte Stufe liegt vor, wenn durch Anordnung, Abmessung und Überwachung der freien Raumheizfläche Behaglichkeitsdefizite (nach Abschnitt 4.2.3) auf Grund baulicher oder betrieblicher Bedingungen vollständig beseitigt sind. Dieses gilt insbesondere als erreicht, wenn

1. die Heizfläche auf Grund ihrer Länge und Anordnung eine Füllfreiheit bringt (Heizkörperlänge = Fensterbreite)

2. ein Strahlungsdefizit in der Anforderungszone nicht auftritt

3. die Raumheizfläche unmittelbar vor derselben Ebene (parallel) wie die „kalte“ Umfassungsfläche angeordnet ist

4. die Ansichtsfäche und die Übertemperatur der Raumheizfläche das Strahlungsdefizit (siehe Abschnitt 5.1.2) der Umfassungsfläche ausgleicht

5. die Raumheizfläche die Normheizlast deckt (DIN pr EN 12 831 bzw. DIN 4701)

6. die vereinbarte Aufheizreserve berücksichtigt ist

Die dritte Stufe liegt ebenfalls vor, wenn baulich keine „kalten“ Umfassungsflächen vorliegen sowie keine störenden Luftströmungen die vorgegebene Anforderungszone erreichen und durch anlagentechnische Maßnahmen die oben genannten Bedingungen 5) und 6) erfüllt sind.

Stufe 2: Teilweise Beseitigung der Behaglichkeitsdefizite

Sie ist dann erreicht, wenn gegenüber Stufe 3 lediglich ein Strahlungsausgleich vorgesehen ist (Anordnung einer freien Raumheizfläche an einer „kalten“ Umfassungsfläche oder unter einem Fenster in nicht ausreichender Länge, oder neben Fenster/Türen). Die Bedingungen für Übertemperatur, Normheizlast sowie Aufheizreserve sind unter Stufe 3 angegeben.

Stufe 1: Deckung der Normheizlast ohne Beseitigung von Behaglichkeits-defiziten⁵

Diese gilt dann als erfüllt, wenn die freie Raumheizfläche lediglich die Normheizlast deckt (DIN pr EN 12 831 bzw. DIN 4701). Hier ist die Anordnung, Art und Größe der Raumheizfläche (Ansichtsfäche) frei wählbar, bei der Wahl der Übertemperatur sind die Grenzwerte nach Abschnitt 5.3 zu beachten. Eine

⁴ In Sinne dieser Richtlinie
⁵ Bei Anforderungenstei umschließt die Anforderungszone automatisch die gesamte Raumfläche

Class 3: Complete compensation of deficits in comfort

Class 3 has been achieved when the arrangement, dimensions and excess temperature of the heating surface are such that deficits in comfort (as per Section 4.2.3) arising from structural or operational conditions are compensated completely. This is particularly assumed to be fulfilled when

1. the length and arrangement of the heating surface are such that it intercepts any downdraft (length of heating appliance approximately equals the length of the window)

2. there is no radiation deficit within the requirements zone

3. the heating surface is arranged directly in front of (and parallel to) the plane of the “cold” enclosing surface

4. the visible-surface area and the excess temperature of the heating surface compensate the radiation deficit (see Section 5.1.2) of the enclosing surface

5. the heating surface covers the design heating load (DIN pr EN 12831 or DIN 4701)

6. the agreed heating-up reserve has been observed

Class 3 has been achieved as well when there are not “cold” enclosing surfaces and interfering air flows remaining outside the specified requirements zone and if the above mentioned conditions 5) respectively 6) are fulfilled by measures of systems engineering.

Class 2: Partial compensation of deficits in comfort

This class is achieved when, in contrast to class 3, provision is only made for radiation deficits to be compensated (by arranging a free heating surface next to a “cold” enclosing surface, or a free heating surface with insufficient length under a window, or a free heating surface to the side of a window/door). The criteria for excess temperature, design heating load and heating-up reserve are as given for class 3.

Class 1: Provision of design heating load without compensation of deficits in comfort⁶

Class 1 is deemed to be achieved when the free heating surface merely covers the design heating load (DIN pr EN 12831 or DIN 4701). Arrangement, type and dimensions of the heating surface (visible surface) can be chosen arbitrarily, limits for the excess temperature as per Section 5.3 shall be observed. A

⁶ as defined in this guideline
⁷ The requirements are for class 1 automatically equals the entire area of the room.
Aufheizreserve ist nicht oder nur zum Teil berücksichtigt, Befähigungsdefizite (nach Abschnitt 4.2.3) können nicht oder nur zum Teil ausgeglichen werden.

4.2.6 Aufheizreserve

Die Aufheizreserve wird definiert als Leistungreserve der Raumheizfläche zum Zweck der Aufheizung eines Raumes aus dem Abschalt-Heizbetrieb heraus. Anhaltswerte für den erforderlichen Leistungsbeitrag, $\phi_{\text{E}}$, liefern DIN pr EN 12 831.

Eine Aufheizreserve kann durch den Einbau einer zusätzlichen, im Normalbetrieb abgestellten Raumheizfläche bereitgestellt werden; sie ist prinzipiell unbegrenzt. Eine derartige Reserve ist im Pfliegenheitsvertrag vorzusehen, insbesondere dann, wenn eine begrenzte Aufheizzeit möglich sein soll.


4.2.7 Zusatzenutzer

In welcher Weise die auszuliegende Raumheizfläche über die Heizfunktion hinaus als Handtuchhalter, Garderobe, Raumteiler oder anders genutzt wird, ist vom Auftraggeber festzulegen. Gegebenenfalls sind aus Gründen der Anordnung und Abmessungen Einschränkungen bei den Anforderungsstufen hinzuzunehmen.

5 Grundlagen für die Auslegung

5.1 Befähigungsdefizite

5.1.1 Untertemperatur „kaften“ Umfassungsfächen

Die für das Strahlungsdefizit bei einer „kaften“ Umfassungsfläche maßgebliche Untertemperatur berechnet sich nach Gleichung (1):

$$\Delta T_{u} = \frac{U_{w}}{\alpha_{g}} (\theta_{A} - \theta_{s})$$

Bei waagrechten bzw. senkrechten Umfassungsflächen sind die Wärmeübergangswiderstände $1/\alpha_{g}$, nach Tabelle 1 einzusetzen.

heating-up reserve is not, or only partially, provided for. Deficits in comfort (as per Section 4.2.3) cannot, or only partially, be compensated.

4.2.6 Heating-up reserve

The heating-up reserve is, by definition, the power reserve of the heating surface, which is available for heating up the room after economy operation of the heating system. Reference values of the required capacity, $\phi_{\text{E}}$, are given in DIN pr EN 12 831.

A heating-up reserve can be provided by installing an additional heating surface that is not used during normal operation. In principle, there is no limitation. Such a reserve shall be specified in the target specification, particularly when heating up is to be completed within a limited period of time.

As it is possible to raise the inlet water temperature and/or the water flow rate beyond the design value(s), there may be a certain heating-up reserve which is limited by the design and system conditions. Appropriate switchgear and control gear must be provided in order to make this reserve available.

4.2.7 Additional use

The orderer shall specify any use of the heating surface to be designed, which goes beyond heating, for instance, if it also serves to hang towels or clothes, to partition a room, etc. If necessary, limitations in the class of requirements must be accepted for reasons of arrangement and dimensions.

5 Fundamentals of designing

5.1 Deficits in comfort

5.1.1 Under temperature of “cold” enclosing surfaces

The under temperature relevant to the radiation deficit caused by one “cold” enclosing surface is calculated as per Equation (1):

$$\Delta T_{u} = \frac{U_{w}}{\alpha_{g}} (\theta_{A} - \theta_{s})$$

Assume heat transfer resistances, $1/\alpha_{g}$, as given in Table 1 for horizontal and vertical enclosing surfaces.
Für die Umfassungsfläche können Anhaltswerte für die sich einstellende Untertemperatur an der Innenseite in Abhängigkeit der Temperaturdifferenz $(\delta_A - \delta_k)$ und des $U$-Wertes der Umfassungsfläche Bild C1 (Anhang C) entnommen werden.

5.1.2 Strahlungsdefizit durch „kalte“ Umfassungsflächen

Das Strahlungsdefizit durch „kalte“ Umfassungsflächen wird ausreichend genau durch einen linearen Ansatz mit $A_U \cdot \Delta T_{UJ}$ beschrieben. Für seinen Ausgleich durch Zustrahlung einer freien Raumbeizfläche gilt einem analogen Ansatz:

$$\Delta T_H \geq \frac{A_U \cdot \Delta T_{UJ}}{\sum H_{HK} \cdot H_{HK}} \quad \text{(2)}$$

Bei mehreren Flächen $j$ und $k$ (in einer Ebene) gilt entsprechend Gleichung (3):

$$\Delta T_H \geq \frac{\sum A_{Uj} \cdot \Delta T_{Uj}}{\sum H_{HK,j} \cdot H_{HK,j}} \quad \text{(3)}$$

Refer to Figure C1 (Annex C) for reference values of the under temperature on the inside of the enclosing surface as a function of the temperature difference $(\delta_A - \delta_k)$ and the $U$-value of the enclosing surface.

5.1.2 Radiation deficit due to “cold” enclosing surfaces

The radiation deficit due to “cold” enclosing surfaces is described to sufficient accuracy by a linear function of $A_U \cdot \Delta T_{UJ}$. Its compensation by means of radiation from a free heating surface is described by an analogous approach:

$$\Delta T_H \geq \frac{A_U \cdot \Delta T_{UJ}}{\sum H_{HK} \cdot H_{HK}} \quad \text{(2)}$$

If several surfaces, $j$ and $k$ (in one plane), are to be considered, use Equation (3):

$$\Delta T_H \geq \frac{\sum A_{Uj} \cdot \Delta T_{Uj}}{\sum H_{HK,j} \cdot H_{HK,j}} \quad \text{(3)}$$
5.1.3 Fallluftströmung an „kalten“ Umfassungsf lächen

Die sich an einer „kalten“ Umfassungsf läche ablösende Luft führt zu einer Fallluftströmung mit Geschwindigkeiten von bis zu 0,3 m/s am Fu ß der F läche und einem breitenabgestuften Luftstrom von z. B. 45 m³/h m² [1] (Beispiel für ein Fenster: 2 m hoch, \( U_w = 1,1 \text{ W/m²K} \), Fenstertemperatur 4,6 K).

5.1.4 Luftströmung durch Zuluft

Luftströmungen durch Zuluft entstehen an Un dich tigkeiten (Infiltration) und Zuluftüberschlägen (Nach strömflächen, z. B. für raumluftabhängige Wär meerzeuger) in der Umfassungsaußent fläche.

Behaglichkeitsdefizite durch Zuluft an Öffnungen zur freien Lüftung müssen durch entsprechende An ordnung von Heizflächen ausgeglichen werden. Hierbei sind DIN 1946-6, DIN 18 017-1-3, die TRGI und die Herstellerangaben zu den Nachström offnungen zu beachten.

5.2 Grö ß en für die Auslegung der tro men Raumheizflächen

5.2.1 Wassertemperatur

Die Wassertemperatur \( \Delta T \) wird bestimmt aus der Differenz von mittlerer Wassertemperatur \( t_m \) und Aus legungs-Innentemperatur \( t_A \) nach Gleichung (4):

\[
\Delta T = t_m - t_A
\]

Sie ist abhängig von der Heizflächenart und etwa gleich der Heizflächenaußentemperatur \( \Delta T_{\text{in}} \). Bei nicht direkter wasserdurchströmter Heizfläche ist die Differenz der Oberflächentemperatur zu berücksichtigen (Herstellerangabe). Für die Auslegung der Heizflä che wird der Wert aus Gleichung (2) bzw. (3) angesetzt.

5.2.2 Auslegungsspreizung

Die Auslegungsspreizung \( \sigma_{\text{self}} \) ist die Differenz zwischen Vor- und Rücklaufwassertemperatur nach Gleichung (5):

\[
\sigma_{\text{self}} = t_1 - t_2
\]

5.2.3 Vorlauf-/Innentemperatur

Die Vorlauf-/Innentemperatur \( \Delta T_1 \) wird als Differenz aus Vorlaufwassertemperatur \( t_1 \) und der Auslegungs-Innentemperatur \( t_A \) nach Gleichung (6) berechnet:

\[
\Delta T = t_1 - t_A
\]
5.2.4 Normheizlast
Als Normheizlast \( Q_N \) eines Raumes wird die Wärmemenge bezeichnet, die dem Raum unter Normwetterbedingungen zugeführt werden muss, damit sich die geforderten thermischen Norm-Innenraumbedingungen einstellen (Norm-Innentemperatur, Auslegungs-Innentemperatur).

Die Normheizlast wird berechnet nach DIN pr EN 12 831 bzw. DIN 4701.

5.2.5 Wärmeleistung
Die Wärmeleistung \( \Phi \) ist die zur Verfügungstehende Wärmemenge je Fläche des Heizflächenanteils. Sie ist über der der Wärmeabgabe der Raumheizfläche im Beharrungszustand. Sie ist entweder der Vorlaufflüssigkeitstemperatur \( \Delta T_L \) und dem Wasserstrom \( Q_w \) oder der Vorlaufflüssigkeitstemperatur \( \Delta T_L \) und der Rücklaufflüssigkeittemperatur \( \Delta T_L \) zugeordnet (siehe 5.2.4). Die erforderliche Auslegungsleistung \( \Phi_{out} \) muss mindestens so groß sein, wie die Normheizlast \( Q_N \).

5.2.6 Norm-Wärmeleistung der Raumheizkörper
Die Norm-Wärmeleistung \( \Phi_0 \) bzw. \( \Phi_0 / \text{Längenbezogene} \) für Raumheizkörper ist nach DIN EN 442-2 die unter folgenden Bedingungen abgegebene Wärmemenge:

- Vorlauftemperatur \( t_1 \geq 75 \, ^\circ\text{C} \)
- Rücklauftemperatur \( t_2 \geq 65 \, ^\circ\text{C} \)
- Bezugs-Lufttemperatur \( t_\text{ref} \geq 20 \, ^\circ\text{C} \)
- Bezugs-Luftdruck \( p_0 \geq 101,3 \, \text{kPa} \)

Sie ist eine Kenngröße für den tatsächlich eingebauten Raumheizkörper (nur in Stufen erhältlich entsprechend Heizkörperkatalog).

5.2.7 Einfluss der Anschlussart auf die Norm-Wärmeleistung der Raumheizkörper

5.2.4 Design heating load
The design heating load, \( Q_N \), is the thermal output to be supplied to a room under standard meteorological conditions to achieve the required standard thermal indoor conditions (standard indoor temperature, design indoor temperature).

The design heating load is calculated in accordance with DIN pr EN 12 831 or DIN 4701.

5.2.5 Thermal output
The thermal output, \( Q \), is the amount of heat per unit time supplied by the heating surface in steady-state operation. It is either associated with the inlet water excess temperature, \( \Delta T_L \), and the water flow rate, \( Q_w \), or with \( \Delta T_L \), and the outlet water excess temperature, \( \Delta T_L \), (see Section 5.2.4). The required design thermal output, \( \Phi_{out} \), must at least equal the design heating load, \( Q_N \).

5.2.6 Standard thermal output of the heating appliances
As per DIN EN 442-2, the standard thermal output, \( \Phi_0 \) or \( \Phi_0 / \text{length} \) (referred to length) of heating appliances is the thermal output under the following conditions:

- Inlet water temperature \( t_1 \geq 75 \, ^\circ\text{C} \)
- Outlet water temperature \( t_2 \geq 65 \, ^\circ\text{C} \)
- Reference air temperature \( t_\text{ref} \geq 20 \, ^\circ\text{C} \)
- Reference air pressure \( p_0 \geq 101,3 \, \text{kPa} \)

The standard thermal output is a characteristic of the heating appliance actually installed in the room (which is only available in units as per the heating appliance catalogue).

5.2.7 Influence of the type of connection on the standard thermal output of heating appliances
The standard thermal output of a heating appliance without forced water flow, as determined in accordance with DIN EN 442, is only valid for inlet at the top and outlet at the bottom, regardless of whether both connections are arranged on the same side or on opposite sides. Where the manufacturer specifies other types of connections, the standard thermal output is determined for those conditions. Depending on the installation, considerable losses in thermal output can occur with any type of connection differing from those mentioned above, or when special valves are fitted. They are the consequence of mixing processes on the water side of the heating appliance, which are taken into account in a simplified way by using the...
5.2.8 Einfluss von Beschichtung und Einbau
Alle Leistungsangaben beziehen sich auf Raumheizkörper mit nichtmetallischen Beschichtungen (Färbung und Lackanstrich). Metallische Beschichtungen (z. B. Metallbronzen) können die Wärmewanderung zwischen Raumheizkörpern mit besseren Strahlungsverhältnissen beträchtlich vermindern (bis zu 50%). Bei Einbau von Radiatoren (Gleichteilheizkörpern, Flächenheizkörpern und ähnlichen) in Nischen oder bei Anordnung von oberen Abdeckplatten ist je nach Heizkörperart mit Leistungsminde rungen gemäß Bild B2-B4 zu rechnen.

5.2.9 Aufheizreserve
Die Aufheizreserve \( \Delta \phi_{HT} \) muss im Pflichtheft vorgegeben sein. Aufheizwerte hierfür liefern DIN pr EN 12831. Die durch Auslegungs- und Anlagenbedingungen (Anhebung der Vorlauftemperatur und/oder des Wasserstroms) gegebene Aufheizreserve \( \Delta \phi_{HT} \) (der Betriebsschichtfläche) errechnet sich aus der Maximalleistung \( \phi_{max} \) abzüglich der Auslegungsleistung \( \phi_{in} \) nach Gleichung (7):

\[
\Delta \phi_{HT} = \phi_{max} - \phi_{in} \tag{7}
\]

Eine durch Zusatzheizfläche (Leistung \( \phi_{ext} \)) hergestellte Aufheizreserve liefert insgesamt (zusammen mit der „Betriebsschichtfläche“):

\[
\phi_{HT} = (\phi_{in} + \phi_{ext}) - \phi_{in} = \Delta \phi_{HT} + \phi_{ext} \tag{8}
\]

Die Gesamtaufheizwärme \( \phi_{HT} \) muss gleich oder größer sein als die mit der Betriebsschichtfläche bereits erreichbare Aufheizwärme \( \Delta \phi_{HT} \).

5.2.10 Wasserstrom
Der Wasserstrom \( q_w \) ist der Wasser-Massenstrom durch die jeweilige Raumheizfläche. Er soll bei Raumheizkörpern aus Gründen einer günstigen Regelbarkeit nicht größer sein als der Wasserstrom bei einer Spezialisierung \( \sigma = \Delta T_w/3 \) oder \( \sigma = 2 \Delta T_w \). Der Gesamtwasserstrom an der Anlage ist die Summe der Einzel-Wasserströme der Raumheizflächen.

5.2.11 Auslegungsdigramm
Im Auslegungsdiagram eines Raumheizkörpers (B14 c3 bis C6, Anhang C) ist der Zusammenhang zwischen Vorläufertemperatur \( \Delta T_w \), Rückläufertemperatur \( \Delta T_r \) und Verhältnis von Wärmeleistung zu Norm-Wärmeleistung \( \delta \phi \) und Wasserstrom zu Norm-Wasserstrom \( q_{w_n} \) dargestellt, siche DIN 4703 T3. Die Kurvenschar des Auslegungsdiagramms ist durch die Bedingung, dass die Leistungsleistung \( \phi \) im Verhältnis der Wasserströme der Raumheizflächen gleich bleibt.

5.2.8 Effects of coating and installation
Information on the thermal output refers to heating appliances with non-metallic coatings (paint or varnish). Metal coatings (such as metallic bronze) can lead to significant reductions in the thermal output of heating appliances where the contribution of radiation is high (up to 50%). Where radiators (sectional radiators, plate radiators and similar heating appliances) are installed in niches, or where cover plates are provided, expect reductions in thermal output depending on the type of heating appliance, as per Figures B2 through B4.

5.2.9 Heating-up reserve
The heating-up reserve \( \Delta \phi_{HT} \) shall be specified in the target specification. Reference values for this quantity are given in DIN pr EN 12831. The heating-up reserve (of the normal-duty heating surface) is provided by the design and system conditions (increase in inlet water temperature and/or water flow rate). \( \Delta \phi_{HT} \) is calculated from the maximum thermal output \( \phi_{max} \) minus the design thermal output \( \phi_{in} \) as per Equation (7):

\[
\Delta \phi_{HT} = \phi_{max} - \phi_{in} \tag{7}
\]

With a heating-up reserve provided by an additional heating surface (thermal output \( \phi_{ext} \)), the total heating-up reserve (additional heating surface plus "normal-duty heating surface") is:

\[
\phi_{HT} = (\phi_{in} + \phi_{ext}) - \phi_{in} = \Delta \phi_{HT} + \phi_{ext} \tag{8}
\]

The total heating-up reserve, \( \phi_{HT} \), must at least equal the heating-up reserve, \( \Delta \phi_{HT} \), afforded by the normal-duty heating surface alone.

5.2.10 Water flow rate
The water flow rate, \( q_w \), is the mass per unit time of water flowing through the heating surface in question. For reasons of good controllability, it shall not be greater than the water flow rate for a difference \( \sigma = \Delta T_w/3 \) or \( \sigma = 2 \Delta T_w \), if possible. The total water flow rate of the system is the sum of the water flow rates through the individual heating surfaces.

5.2.11 Design diagram
The design diagram of a heating appliance (see Figures C3 through C6 in Annex C) illustrates the relation between the inlet and outlet water excess temperatures, \( \Delta T_i \) and \( \Delta T_o \) respectively, to the ratios of thermal output over standard thermal output, \( \delta \phi \), and of water flow rate over standard water flow rate, \( q_{w_r}/q_{w_n} \). See DIN 4703-3. The set of curves in the de-
6 Designing of heating appliances

By way of example, the designing of heating appliances (which are effective as radiators) is described below for class 3 requirements. In the example, only the window is considered as a surface impairing comfort. Designing for classes 1 and 2 is contained in this description insofar as they only require compliance with some of the requirements of class 3. Annex E gives a calculation example for this.

6.1 Determination of the length and height of the heating appliance

The heating appliance must at least comply with the following requirements in order to counter the downdraft on the inside of the window:

1. The heating appliance must be arranged under the window.
2. The length of the heating appliance must approximately equal that of the window.
3. The height of the heating appliance may be chosen arbitrarily to match aesthetic and architectural requirements.

The calculation of radiation compensation will be omitted for heating appliances which are not effective as radiators, e.g., convectors. The inlet water temperature is either determined by the remaining radiators, or may be chosen arbitrarily.
6.2 Berechnung der benötigten Raumheizkörper-Übertemperatur

Zur Kompensation der „kalten“ Abstrahlung z. B. eines Fensters sind von dem Raumheizkörper folgende Bedingungen zu erfüllen:

Anordnung des Raumheizkörpers vor der gleichen Ebene wie das Fenster,

\[
\Delta T_{H, k} \geq \frac{L_{W, H} \cdot H_{U, k} \cdot \Delta T_{W}}{H_{H, k}} (9)
\]

Die Fensterabstrahltemperatur \( \Delta T_W \) im Auslegungsfall ergibt sich nach Gleichung (1) mit der Außen-temperatur \( \varphi_e \) entsprechend DIN pr EN 12 831 bzw. DIN 4701 oder kann entsprechend aus Bild C1 (Anhang C) entnommen werden. Die höchste der verschiedenen Übertemperaturen \( \Delta T_{H, max} \) dient der Auslegung.

6.3 Bestimmung der Spreizung, Vor- und Rücklaufübertemperatur im Auslegungsfall

Die minimale Auslegungsspreizung \( \sigma_{min} \) soll bei Raumtemperaturreglern mit gleichbleibender Regelabweichung (z. B. Thermostatenventile mit P-Verhalten) nach Bild C2 in Abhängigkeit der Wasserlaufentemperatur \( \Delta T_t \) nicht unterschritten werden. Die Auslegungs-Vorlaufübertemperatur \( \Delta T_t \) wird nach Gleichung (10) aus der Summe der maximal notwendigen Raumheizflächen-Überwassertemperatur \( \Delta T_{H, max} \) und der halben Auslegungsspreizung \( \frac{\sigma_{min}}{2} \) berechnet. Die Auslegungs-Rücklaufübertemperatur ergibt sich aus der Differenz zwischen Auslegungs-Vorlaufübertemperatur \( \Delta T_t \) und Auslegungsspreizung \( \sigma_{min} \) nach Gleichung (11):

\[
\Delta T_t = \Delta T_{H, max} + \frac{\sigma_{min}}{2} (10)
\]

\[
\Delta T_t = \Delta T_t - \frac{\sigma_{min}}{2} (11)
\]

Entsprechend Abschnitt 5.3 ist die Auslegungs-Vorlaufentemperatur nach oben und unten beschränkt.

6.4 Bestimmung der Norm-Wärmeleistung

Dem Auslegungsdiagramm Bild C3-C6 (Anhang C) kann mit der Vor- und Rücklaufübertemperatur des Raumheizkörpers das Verhältnis \( \Delta T_{H, max} \) entnommen werden. Mit Hilfe der Normheizlast \( \varphi_{N} \) (bei mehreren Heizkörpern in einem Raum soll die Normheizlast entsprechend der Anschnittfläche der Heizkörper aufgeteilt werden, lässt sich dann die geforderte Norm-Wärmeleistung \( \varphi_{N, H} \) des Raumheiz-

6.2 Determination of the required excess temperature of the heating appliance

In order to compensate the "cold" radiation of, e. g., a window, the heating appliance \( h \) must fulfill the following requirements:

Heating appliance arranged in front of the window plane:

\[
\Delta T_{H, k} \geq \frac{L_{W, H} \cdot H_{U, k} \cdot \Delta T_{W}}{H_{H, k}} (9)
\]

The design window under temperature, \( \Delta T_{W} \), is calculated from Equation (1) using the outdoor temperature, \( \varphi_e \), as per DIN pr EN 12 831 or DIN 4701, or may be obtained from Figure C1 (Annex C). The highest of the various excess temperatures, \( \Delta T_{H, max} \), is used for designing purposes.

6.3 Determination of design difference between inlet and outlet water temperatures, and design inlet and outlet water excess temperatures

When using room thermostats with a steady-state deviation (such as thermostatic valves with proportional, or P, action), the minimum design difference between inlet and outlet water temperatures should not be less than the value given in Figure C2 as a function of the water excess temperature, \( \Delta T_t \). The design inlet water excess temperature, \( \Delta T_t \), is determined using Equation (10), from the sum of the maximum required heating-surface excess temperature, \( \Delta T_{H, max} \), and half the design difference between inlet and outlet water temperatures, \( \sigma_{min} \). The design outlet water excess temperature results from the difference between the design inlet water excess temperature, \( \Delta T_t \), and the design difference between inlet and outlet water temperatures, \( \sigma_{min} \), as per Equation (11):

\[
\Delta T_t = \Delta T_{H, max} + \frac{\sigma_{min}}{2} (10)
\]

\[
\Delta T_t = \Delta T_t - \frac{\sigma_{min}}{2} (11)
\]

Upper and lower limits of the design inlet water temperature are given in Section 5.3.

6.4 Determination of standard thermal output

The ratio \( \frac{\sigma_{mil}}{\sigma_{mil}} \) can be obtained from the design diagrams in Figures C3 through C6 (Annex C) with the inlet and outlet water excess temperatures of the heating appliance being input quantities. Putting in the design heating load, \( \varphi_{N} \) (where there are several heating appliances in a room, each should be allocated a design heating load in proportion to its visible-surface area), the required standard thermal...
6.5 Auswahl des Heizkörpermodells und Überprüfung der Ergebnisse auf Einhaltung des Gesamziel

Durch die Abstufung der Leistungsangaben im jeweiligen Raumheizkörper-Katalog wird in der Regel eine gegenüber $\varphi_{w_{,\text{eff}}}$ niedrigere Norm-Wärmeleistung $\varphi_{3 \text{, Min}}$ ausgewählt, damit die mittlere Übertemperatur der Heizfläche nicht unter den nach Gleichung (9) errechneten Wert von $\Delta T_{\text{H}}$ sinkt. Dies führt bei festgehalteiner Auslegungs-Vorlauftemperatur zu einer Anhebung der Heizkörper-RücklaufTemperatur und des Wasserstroms oder bei festgehaltener Spreizung zur Anhebung der Vor- und RücklaufTemperatur.

Zur Überprüfung der Kompensation der „kalten“ Abstrahlung der Umfassungslagen muss Gleichung (13) erfüllt sein:

$$\Delta T_{\text{H, i, is}} = \frac{\Delta T_{1} + \Delta T_{2 \text{, Min}}}{2} \geq \Delta T_{\text{H}}$$

(13)

6.5 Berechnung des Wasserstroms

Die Auslegelast $\varphi_{\text{eff}}$ und die 1. Spreizung $\sigma_{1}$ bestimmen den Wasserstrom nach Gleichung (14):

$$q_{m} = \frac{\varphi_{\text{eff}}}{\sigma_{1} \cdot c_{p}}$$

(14)

6.6 Berechnung der Aufheizreserve

Zur Berechnung der Aufheizreserve wird das Verhältnis $\Delta q_{\text{Min}} / \varphi_{w}$ aus dem Auslegediagram (Bild C3-C6) bei der maximal erreichbaren Vorlauftemperatur und dem maximal erreichbarer Wasserstrom abgelesen. Entsprechend wird bei der Zusatzheizfläche vorgegangen.

Schrifttum


Bibliography


Annex A  Target specification for heating systems

Project:

Building:

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$^7$ calculated value of transmission and ventilation heating load as per DIN 4108 or DIN pr EN 12 831

$^6$ The border between low and high loss as internal load/design heating load ratio of more than 0.2.

$^5$ Enter additional information on the supply air flow where forced-draft ventilation is used; otherwise only classify as m (for mechanical) or w (for window).

$^4$ distance in meters to cold enclosing surface

$^3$ as per DIN pr EN 12 831

$^2$ effort number of benefit transfer as per VDI 2047 Part 20

Date ............................ Orderer ............................

Date ............................ Orderer ............................
Anhang B Algorithmen zum Auslegungsdiagramm
Bes der Leistungsansprache DIN EN 442-2 wird die so genannte Norm-Kennlinie festgestellt:

\[ \phi = C \cdot \Delta t \]

(B1)

mit

\[ \Delta t = \frac{t_1 + t_2}{2} - t_r \]

(B2)

oder

\[ \phi = \left( \frac{\Delta t}{\Delta t_{\text{N}}} \right)^n \]

(B3)

mit

\[ \Delta t_{\text{N}} = \theta_{\text{max}} \cdot C_p \cdot \left( t_1 - t_2 \right)_h = \theta_{\text{max}} \cdot C_p \cdot \Delta T \]

(B4)

Abweichungen von der Normkennlinie treten auf, wenn
- der Wassersstrom stark unter den Norm-Wassersstrom gedrosselt oder
- vom üblichen Anschluss (oben Vorlauf, unten Rücklauf) abweichen wird.

Diese Einflüsse lassen sich rechnerisch erfassen unter der Annahme eines linearen Zusammenhangs innerhalb des Heizkörpers stark vereinfachender Modells, als Temperatur des Beimischwassersstroms \( q_2 \) wird die des Rücklaufs angenommen. Die Mischung bewirkt, dass die höchste Temperatur im Heizkörper \( t_{\text{eff}} \) unterhalb der Vorlaufstemperatur liegt.

\[ \theta_{\text{max}} \cdot \frac{t_1 + t_2}{2} = (\theta_{\text{max}} + q_2) \cdot t_{\text{eff}} \]

(B5)

\[ t_{\text{eff}} = \frac{t_1 + (b - 1) \cdot t_2}{b} \]

(B6)

Der die Mischungswärme pauschal erfassende Beimischwert \( b \) liegt für Gliederheizkörper und Plattenheizkörper bei etwa 1,25, bei reitendem Anschluss kann er auf Werte von 7 und darüber ansteigen. Nach DIN 4703-3 können vereinfachende Annahmen getroffen werden, solange keine gemessenen Werte vorliegen:
- für Heizkörper mit oberem Verlaufanschluss, horizontaler Verteilung und vertikaler Durch- oder Zwangsdruckströmung \( b = 1 \),
- für Heizkörper mit reitendem Anschluss, horizontaler Verteilung und vertikaler Durchströmung \( b = 8 \).

Annex B Algorithms of the design diagram
The so-called standard characteristic is determined by measuring the thermal output according to DIN EN 442-2:

\[ \phi = C \cdot \Delta t \]

(B1)

where

\[ \Delta t = \frac{t_1 + t_2}{2} - t_r \]

(B2)

or

\[ \phi = \left( \frac{\Delta t}{\Delta t_{\text{N}}} \right)^n \]

(B3)

where

\[ \Delta t_{\text{N}} = \theta_{\text{max}} \cdot C_p \cdot \left( t_1 - t_2 \right)_h = \theta_{\text{max}} \cdot C_p \cdot \Delta T \]

(B4)

Deviations from the standard characteristic will occur when
- the water flow rate is reduced considerably below the standard water flow rate, or
- there are deviations from the typical type of connection (such as inlet at the top, outlet at the bottom).

A model that largely simplifies the complex mixing processes occurring in a heating appliance allows to take these effects into consideration in calculations, assuming that the temperature of the added water flow rate \( q_2 \) is the same as the outlet water temperature. As a consequence of mixing, the highest temperature in the heating appliance, \( t_{\text{eff}} \), lies below the inlet water temperature.

\[ q_{\text{in}} \cdot t_1 + q_2 \cdot t_2 = (q_{\text{in}} + q_2) \cdot t_{\text{eff}} \]

(B5)

\[ t_{\text{eff}} = \frac{t_1 + (b - 1) \cdot t_2}{b} \]

(B6)

The mixing coefficient, \( b \), which subsumes the mixing processes, is approximately 1.25 for sectional and plate radiators. It can rise to values of 7 and beyond with both inlet and outlet connected at the bottom of the heating appliance. According to DIN 4703-3, the following simplifying assumptions may be made where no measured values are available:
- \( b = 1 \) for heating appliances where the inlet is connected at the top, distribution is horizontal, and the (natural or forced) flow through the heating appliance is vertical,
- \( b = 8 \) for heating appliances where both inlet and outlet are connected at the bottom, distribution is horizontal, and flow through the heating appliance is vertical,
\[
\Delta T_{\text{eff}} = \frac{t_{1\text{eff}} - t_2}{\ln \frac{t_{1\text{eff}} - t_f}{t_2 - t_f}}
\]  
(B7)

Schließlich wird angenommen, dass auch der Zusammenhang zwischen der Wärmeleistung und dieser logarithmischen Übertemperatur durch eine Potenzfunktion zu beschreiben ist, allerdings mit etwas veränderter Hochzahl \( n_{\text{eff}} = 1,33 \).

\[
\left[ \frac{\Phi}{\Phi_0} \right]^{\frac{1}{n_{\text{eff}}}} = \frac{b \cdot \Delta T_{\text{eff}}}{\Delta T_1 - \Delta T_2} \left( \ln \left( \frac{b - 1}{b} + \frac{\Delta T_1}{\Delta T_2} \right) \right)
\]  
(B8)

Mit den vorgenannten Annahmen ist nun ein Zusammenhang zwischen der Wärmeleistung und den Übertemperaturen angegeben.

Diese Formel liegt dem so genannten Heizkörperdiagramm zu Grunde; für den Beimischwert ist hier \( b = 1,0; b = 1,25 \) (für genaue Rechnungen); \( b = 8 \) und \( b = 10 \) eingesetzt; für die Hochzahl gilt einheitlich \( n_{\text{eff}} = 1,33 \). Das gleiche Diagramm kann auch für von 1,33 abweichende Hochzahlen verwendet werden nach:

\[
\left[ \frac{\Phi}{\Phi_0} \right]^{\frac{1}{n_{\text{eff}}}} = \left( \frac{\Phi}{\Phi_0} \right)^{\frac{1,33}{n_{\text{D}}}}
\]  
(B9)

\[
\left[ \frac{\Phi}{\Phi_0} \right]^{\frac{1}{n_{\text{eff}}}} = \left( \frac{\Phi}{\Phi_0} \right)^{\frac{1,33}{n_{\text{D}}}}
\]  
(B9)

\[
\Delta T_{\text{eff}} = \frac{t_{1\text{eff}} - t_2}{\ln \frac{t_{1\text{eff}} - t_f}{t_2 - t_f}}
\]  
(B7)

Finally, the assumption is made that the relation between the thermal output and this logarithmic excess temperature can also be described in terms of an exponential function, although with a slightly modified power \( n_{\text{eff}} = 1,33 \).

A relation between the thermal output and the excess temperatures can then be given on the basis of the aforementioned assumptions. This is the formula underlying the so-called heating-appliance diagrams. Values of the mixing coefficient, \( b = 1,0; b = 1,25 \) (for more precise calculations), \( b = 8 \), and \( b = 10 \) were used. The power \( n_{\text{eff}} \) is 1,33 in all cases. However, the same diagram can be used for powers other than 1,33, using:

\[
\left[ \frac{\Phi}{\Phi_0} \right]^{\frac{1}{n_{\text{eff}}}} = \left( \frac{\Phi}{\Phi_0} \right)^{\frac{1,33}{n_{\text{D}}}}
\]  
(B9)

\[
\left[ \frac{\Phi}{\Phi_0} \right]^{\frac{1}{n_{\text{eff}}}} = \left( \frac{\Phi}{\Phi_0} \right)^{\frac{1,33}{n_{\text{D}}}}
\]  
(B9)
Fig. B1. Installation of heating appliances: BA is the distance from the floor, WA the distance from the wall, and NA the distance from the niche.

Fig. B2. Reduction in thermal output as a function of the distance between the heating appliance and the lower edge of the niche.
Bild B3: Leistungsminderung in Abhängigkeit vom Wandabstand des Heizkörpers

Fig. B3. Reduction in thermal output as a function of the distance between the heating appliance and the wall.

Bild B4: Leistungsminderung in Abhängigkeit vom Bodenabstand des Heizkörpers

Fig. B4. Reduction in thermal output as a function of the distance between the heating appliance and the floor.
Bild C1: Untertemperatur einer Umfassungsfläche (z. B. eines Fensters) in Abhängigkeit von der inneren Übertemperatur

\[ \Delta T_I = \theta_I - \theta_{I_{in}} - \theta_{I_{out}} \text{ in K} \]

Fig. C1. Under temperature of an enclosing surface (such as a window) as a function of indoor excess temperature

Bild C2: Mindest-Auslegungsspannung für

\[ \frac{\Delta T_I}{\sigma} = 3,0 \]

Fig. C2. Minimum design difference between inlet and outlet water temperatures for

\[ \frac{\Delta T_I}{\sigma} = 3,6 \]
Fig. C3. Heating-surface design diagram, for \( n = 1.33 \), \( b = 1.0 \) (as per DIN 4703-3 for heating appliances with inlet connected at the top, horizontal distribution, and vertical, natural or forced flow).

Fig. C4. Heating-surface design diagram, for \( n = 1.33 \), \( b = 1.25 \) (inlet and outlet connected on the same side or on opposite sides, prismatic design).

Fig. C5. Heating-surface design diagram for $n = 1.33$, $b = 8$ (as per DIN 4703-3 for heating appliances with both inlet and outlet connected at the bottom, horizontal distribution, and vertical flow).


Fig. C6. Heating-surface design diagram for $n = 1.33$, $b = 10$ (as per DIN 4703-3 for heating appliances with both inlet and outlet connected at the bottom, vertical distribution, and horizontal flow, such as bathroom heating appliances).
Anhang D Rechnerische Bestimmung der Grenzfläche von Anforderungszonen

Um die Wirkung eines Heizsystems auf die Behaglichkeit zu bestimmen, gehören die konvektiven und radiativen Wärmeverluste eines Oberflächenelements einer Person zu betrachten, siehe Bild D1. Dabei wird die von einem Heizsystem (z.B. Raumheizflächen) beeinflusste thermische Umgebung (Realfall) Lufttemperatur \( \delta_a \), Oberflächentemperaturen der Außenwände mit Fenster \( \delta_{aw} \), Innenwände \( \delta_{iw} \) oder Heizfläche \( \delta_h \) verglichen mit einer zum Zwecke der Auslegung vorgesehenen Einfachsituation, bei der alle Temperaturen gleich sind \( \delta^* = \delta_a = \delta_{aw} = \delta_{iw} \) und Behaglichkeit gemäß DIN ISO 7730 herrscht. Das betrachtete Oberflächenelement \( dA_h \) sei in der für die Behaglichkeitsempfindung kritischen Position, parallel zur „kalten“ Umfassungsfläche (Index AW) angeordnet. Vereinfacht sind die so gegebenenfalls verschiedenen kalten Umfassungsflächen (AW) und auch die wärmen Innennflächen (IW) je zu einer zusammengefasst. Die Einstrahlzahlen \( q \) gekennzeichnet durch die Indizes der im Strahlungsaustausch stehenden Flächen, geben den durch die Größe und geometrische Zuordnung begrenzten Anteil des Strahlungsstatmutes an. Bei dem vorliegenden Temperaturintervall und den eng beieinander liegenden Temperaturen kann für den Wärmestrom durch Strahlung ein linearer Zusammenhang mit einem Wärmestromkoeffizienten \( a_w = 5.15 \, \text{W/m}^2\text{K} \) angenommen werden. Vereinfachend gelte einheitlich für den konvektiven Wärmestromkoeffizienten \( a_c = 3 \, \text{W/m}^2\text{K} \).

Die Wärmestromdichte \( \frac{dQ}{dA_h} \) beträgt beim Austausch mit der „kalten“ Außenwand (AW), der Innenwand (IW), der Heizfläche (H) und der Raumluft (L):

\[
\frac{dQ}{dA_h} = a_w \cdot (\delta_h - \delta_h) + \alpha_c \cdot (\delta_{aw} - \delta_h) + \alpha_h \cdot (\delta_h - \delta_{aw}) + (1 - \alpha_{SL,AW} - \alpha_{SL,H}) \cdot (\delta_h - \delta_{tw}) \tag{D1}
\]

Bei der vorgegebenen Idealisation ist die Wärmestromdichte

\[
\left( \frac{dQ}{dA_h} \right)^* = (\delta_h - \delta^*) \cdot (\alpha_h + \alpha_c) \tag{D2}
\]

Annex D Calculation of the boundary surfaces of requirements zones

For assessing the effect of a heating system on comfort, it is sufficient to consider the loss of heat, by convection and radiation, from a body surface element, see Figure D1. For the purposes of this consideration, a thermal environment where the actual temperatures are \( \delta_a \) (air), \( \delta_{aw} \) (exterior walls with windows), \( \delta_{iw} \) (interior walls), and \( \delta_h \) (heating surface) which is influenced by a heating system (such as heating surfaces) is compared with a simplified situation that is specified for design purposes. In this simplified situation, all temperatures are identical \( \delta^* = \delta_a = \delta_{aw} = \delta_{iw} \), and thermal comfort as per DIN ISO 7730 exists. The surface element in question, \( dA_h \), lie at the position which is critical for the feeling of comfort, i.e. parallel to the “cold” enclosing surface (subscript AW). For simplification purposes, cold enclosing surfaces (AW) as well as the warmer interior surfaces (IW) are treated as one surface of each type. (Several different surfaces of both types may exist.) The radiation coefficients, \( q \), with subscripts identifying the respective surfaces between which radiation is exchanged, indicate the exchange of radiation as limited by the dimensions and the geometrical arrangement of the surfaces. For the temperatures in question, which do not differ greatly, a linear function with a heat transfer coefficient \( a_w = 5.15 \, \text{W/m}^2\text{K} \) can be assumed to hold for the exchange of heat by radiation. For simplification, let \( a_c = 3 \, \text{W/m}^2\text{K} \) for convection.

The heat flow density \( \frac{dQ}{dA_h} \) for exchange with the “cold” exterior wall (AW), the interior wall (IW), the heating surface (H), and the indoor air (L) is:

\[
\left( \frac{dQ}{dA_h} \right) = a_w \cdot (\delta_h - \delta_a) + \alpha_c \cdot (\delta_{aw} - \delta_a) + \alpha_h \cdot (\delta_h - \delta_{aw}) + (1 - \alpha_{SL,AW} - \alpha_{SL,H}) \cdot (\delta_h - \delta_{tw}) \tag{D1}
\]

The heat flow density in the assumed idealised situation is

\[
\left( \frac{dQ}{dA_h} \right)^* = (\delta_h - \delta^*) \cdot (\alpha_h + \alpha_c) \tag{D2}
\]
Der Wärmeabgabeveergleich lautet:

\[
\left( \frac{\partial Q_w^*}{\partial t_M} \right) - \left( \frac{\partial Q_w}{\partial t_M} \right) = \sigma_k \cdot (s_{M} - s_{M}^*) + \alpha_k \cdot \left( \phi_{MAH} \cdot (s_{M} - s_{M}^*) \right) + (1 - \phi_{MAW} - \phi_{MAH}) \cdot (s_{MAW} - s_{M}^*) - \phi_{MAW} \cdot (s_{M}^* - s_{MAW}) \]  

(D3)

Der Wärmeabgabeveergleich wird beispielhaft berechnet für einen Raum, der 4 m breit, 5 m tief und 2,5 m hoch ist.

Als Heizfläche sei eine einfache Heizfläche von 0,5 m Höhe und 4 m Breite angenommen; die mittlere Oberflächentemperatur soll 52 °C betragen. Die mittlere Temperatur der restlichen Außenwandfläche sei hier 12 °C, die Temperatur der Innenwände und der Luft 20 °C.

Mit der Heizfläche wird das Strahlungsdefizit durch die „kalte“ Umfassungsfläche (Fenster) ausgeglichen, wenn Gleichung (D4) gilt:

\[
\left( \frac{\partial Q_w^*}{\partial t_M} \right) - \left( \frac{\partial Q_w}{\partial t_M} \right) = 0 \]  

(D4)

Gleichung (D3) ergibt mit den beispielhaft gegeben Werten:

\[
\frac{3 \cdot W}{m^2 \cdot \text{K}} (20 \degree C - 20 \degree C) + 5,15 \cdot \frac{W}{m^2 \cdot \text{K}} \\
\left[ \frac{\phi_{MAH} \cdot (20 \degree C - 20 \degree C)}{(1 - \phi_{MAW} - \phi_{MAH}) \cdot (20 \degree C - 20 \degree C)} \right] - \phi_{MAW} (20 \degree C - 12 \degree C)] = 0
\]  

(D5)

oder:

\[
4 \phi_{MAH} - \phi_{MAW} = 0 \]  

(D6)


The difference in heat losses is:

\[
\left( \frac{\partial Q_w^*}{\partial t_M} \right) - \left( \frac{\partial Q_w}{\partial t_M} \right) = \sigma_k \cdot (s_{M} - s_{M}^*) + \alpha_k \cdot \left( \phi_{MAH} \cdot (s_{M} - s_{M}^*) \right) + (1 - \phi_{MAW} - \phi_{MAH}) \cdot (s_{MAW} - s_{M}^*) - \phi_{MAW} \cdot (s_{M}^* - s_{MAW}) \]  

(D3)

By way of example, the difference in heat losses is calculated for a room that is 4 m in width, 5 m in length and 2,5 m high.

The assumed heating surface is a simple heating plate, 0,5 m high and 4 m wide. Let its mean surface temperature be 52 °C, the mean temperature of the remaining exterior-wall surface 12 °C, and the temperature of interior walls and air 20 °C.

The heating surface will compensate the radiation deficit caused by the “cold” enclosing surface (window) if Equation (D4) holds true:

\[
\left( \frac{\partial Q_w^*}{\partial t_M} \right) - \left( \frac{\partial Q_w}{\partial t_M} \right) = 0 \]  

(D4)

Using the values given as examples, Equation (D3) gives:

\[
\frac{3 \cdot W}{m^2 \cdot \text{K}} (20 \degree C - 20 \degree C) + 5,15 \cdot \frac{W}{m^2 \cdot \text{K}} \\
\left[ \frac{\phi_{MAH} \cdot (52 \degree C - 20 \degree C)}{(1 - \phi_{MAW} - \phi_{MAH}) \cdot (20 \degree C - 20 \degree C)} \right] - \phi_{MAW} (20 \degree C - 12 \degree C)] = 0
\]  

(D5)

or:

\[
4 \phi_{MAH} - \phi_{MAW} = 0 \]  

(D6)

The radiation coefficients needed for illustration of the boundary surfaces may, e.g., be taken from the VDI Wärmeatlas [2]. For the above example, the boundary surface of the requirements zone is illustrated in Figure D2.
Bild D1: Person im Strahlungsauktausch
Fig. D1: Heat-exchange of a person

Bild D2: Beispiel für die Grenzfläche der tatsächlich herstellbaren Anforderungszone (mit Anforderungsstufe 3), die vereinfachten geraden Grenzflächen der Anforderungszone für das Prüfenheiz zeigt Bild 1
Fig. D2: Example of boundary surface of actually achievable requirements zone (with class 3 requirements), the simplified linear boundary surfaces of the requirements zone used in the target specification are shown in Figure 1.
Anhang E Konzeptionsbeispiele und Beispielerrechnung

Konzepionsbeispiel 1: Aufenthaltsraum

Vorgabe:
- Anforderungsstufe 3 (Oberflächentemperatur der „kalten“ Umfassungsfläche 4 K kälter als Auslegungsinnentemperatur)
- Maximal ausgehend aus Anforderungszone (Abstand zur „kalten“ Umfassungsfläche 1 m)
- Anheizreserve nach DIN pr EN 12831: $\varphi_{\text{hot}} = 30 \text{ W/m}^2$

Ausführung:
Heizkörper unter dem Fenster (siehe 4.2.5, Anforderungsstufe 3)

Alternative Ausführung:
Wäre ein Konvector (ohne Strahlungswirkung) eingebaut oder der Heizkörper an der Innenwand angebracht, könnte nur Anforderungsstufe 1 erreicht werden (also Vorgabe nicht eingehalten).

---

Annex E Design examples and example calculation

Design example 1: Day room

Specification:
- Class 3 requirements (surface temperature of “cold” enclosing surface 4 K less than design indoor temperature)
- Maximum extension of requirements zone (distance to “cold” enclosing surface: 1 m)
- Heating-up reserve as per DIN pr EN 12831: $\varphi_{\text{hot}} = 30 \text{ W/m}^2$

Realisation:
Heating appliance below window (see Section 4.2.5, class 3 requirements)

Alternative specification:
If a convector were used (no heat radiation), or if the heating appliance were installed on the interior wall, only class 1 requirements could be fulfilled (which means that the specification would not be met).
Design example 2: Comfortable living-room

Specification:
- Class 3 requirements (surface temperature of “cold” enclosing surface 4 K less than design indoor temperature)
- The requirements zone is determined by the room design (maximum possible height of heating appliances) and the intended use, see Figure

Realisation:
Heating appliances below the windows and to the side of the door leading to the terrace (see Section 4.2.5, class 3 requirements). The greater distance from window 1 allows compensating the radiation deficit due to window 1 and the deficit due to the downdraft at the door leading to the terrace; class 3 requirements are fulfilled within the requirements zone. (It could be shown using Annex D that the distance of 2 m is sufficient here.)

Alternative specification:
If the distance to the “cold” enclosing surface in the area of window 1 were to be reduced to 1 m, the requirements zone thus expanded would only allow to fulfil class 2 requirements.

---

Alternative Vorgabe:
Soll der Abstand zur „kalten“ Umfassungsfläche im Bereich des Fenster 1 nur 1 m betragen wäre mit der so vergrößerten Anforderungszone nur Anforderungsstufe 2 einzuhalten.
Konzeptionsbeispiel 3: Zimmer im Studentenwohnheim

Vorgabe:
- Anforderungsstufe 2
- Anforderungzone ergibt sich aus Raumgestaltung und vorgegebener Nutzung, siehe Zeichnung.

Ausführung:
Heizkörper zwischen Fenster und Terrassenf&uuml;r (siehe Abschnitt 4.2.5, Anforderungsstufe 2).

Alternative Ausführung:
Durch die Montage des Heizk&ouml;rpers an der Innenswand k&ouml;nnte nur Anforderungsstufe 1 erreicht.

Design example 3: Room in a student hostel

Specification:
- Class 2 requirements
- The requirements zone is determined by the room design (maximum available height of heating appliances) and the intended use, see Figure.

Realisation:
Heating appliances between the window and the door to the terrace (see Section 4.2.5, class 2 requirements).

Alternative specification:
Installing a heating appliance on the interior wall would only allow to fulfil class 1 requirements.
Beispielrechnung

**Aufgabe:**
Für den Aufenthaltsraum aus Konzeptionsbeispiel 1 mit den angeführten Vorgaben soll die Raumheizfläche ausgelegt werden.

**Vorgegebene Daten:**

**Auslegungs-Innentemperatur:**
\[ \theta_A = 22 \, ^\circ\text{C} \]

**Normheizlast:**
\[ \dot{Q}_N = 760 \, \text{W} \]

**Raummaße:**
- Breite: 4 m
- Tiefe: 5 m
- Höhe: 2,5 m

**Fenstermaße:**
- Breite \( L_{fen} = 2 \, \text{m} \)
- Höhe \( H_{fen} = 1,5 \, \text{m} \)

**Fenster:**
- \( U \)-Wert \( U_{fen} = 1,3 \, \text{W/(m}^2\text{K)} \)
- Wärmeübergangswiderstand \( 1/\alpha = 0,13 \, \text{(m}^2\text{K})/\text{W}) \)
  (aus Tabelle 1)

**Außenbedingungen:**

**Außentemperaturen:**
- \( \theta_x \) = -14 \, ^\circ\text{C} \)

**Heizreserve nach DIN pr EN 12 831:**
\[ \dot{Q}_{Res} = 30 \, \text{W/m}^2 \]

**Auslegung des Raumheizkörpers:**

1. Festlegen der Anordnung und Länge der Raumheizfläche:
   - Anordnung der Raumheizfläche unter dem Fenster
   - Länge Raumheizfläche \( L_{HK} = 2 \, \text{m} \)
   - Höhe der Raumheizfläche (gewählt) \( H_{HK} = 0,5 \, \text{m} \)

2. Berechnung der benötigten Raumheizflächen-Übertemperatur:
\[ \Delta T_U = \frac{U}{\alpha} (\theta_{x,A} - \theta_A) \]

**Example calculation**

**Problem:**
To design a heating surface fulfilling the specifications listed for the day room in example 1.

**Specifications:**

**Design indoor temperature:**
\[ \theta_A = 22 \, ^\circ\text{C} \]

**Design heating load:**
\[ \dot{Q}_N = 760 \, \text{W} \]

**Dimensions of the room:**
- Width: 4 m
- Length: 5 m
- Height: 2,5 m

**Dimensions of window:**
- Width \( L_{fen} = 2 \, \text{m} \)
- Height \( H_{fen} = 1,5 \, \text{m} \)

**Window:**
- \( U \)-value \( U_{fen} = 1,3 \, \text{W/(m}^2\text{K)} \)
- Heat transfer resistance \( 1/\alpha = 0,13 \, \text{(m}^2\text{K})/\text{W}) \)
  (from Table 1)

**Outdoor temperature:**
- Design case \( \theta_x = -14 \, ^\circ\text{C} \)

**Heating-up reserve as per DIN pr EN 12 831:**
\[ \dot{Q}_{Res} = 30 \, \text{W/m}^2 \]

**Designing of heating appliance:**

1. Specification of arrangement and length of the heating surface:
   - heating surface arranged under the window
   - length of heating surface equals length of window:
     \( L_{HK} = 2 \, \text{m} \)
   - height of heating surface (chosen)
     \( H_{HK} = 0,5 \, \text{m} \)

2. Calculation of required temperature of heating surface:
\[ \Delta T_U = \frac{U}{\alpha} (\theta_{x,A} - \theta_A) \]
3. Auslegungsspezifizierung:

- aus Bild C2
\[ \sigma_{\text{And}} = 7.5 \, \text{K} \]

4. Vorlauf-Übertemperatur aus Gl. (10):
\[
\Delta T_{1,\text{pl}} = \Delta T_{1,\text{max}} + \frac{\sigma_{\text{And}}}{2}
\]
\[ \Delta T_{1,\text{pl}} = 22.05 \, \text{K} \]
da \[ t_{1,\text{min}} = 45 \, ^{\circ}\text{C} \]
\[ \Delta T_{1,\text{pl}} = 55 \, ^{\circ}\text{C} - 22 \, ^{\circ}\text{C} \]
\[ \Delta T_{1,\text{pl}} = 23 \, \text{K} \]

5. Rücklauf-Übertemperatur aus Gl. (11):
\[
\Delta T_{2,\text{pl}} = \Delta T_{1,\text{pl}} - \sigma_{\text{And}}
\]
\[ \Delta T_{2,\text{pl}} = 23 \, \text{K} - 7.5 \, \text{K} \]
\[ \Delta T_{2,\text{pl}} = 15.5 \, \text{K} \]

6. Bestimmung der Normwärmeleistung

- aus Heizkörperauslegungsdiagramm Bild C3
\[ \Phi / \phi_h = 0.28 \]

- Normwärmeleistung nach Gl. (12):
\[
\phi_h = \frac{Q_d}{\phi_{h,\text{eff}}}
\]
\[ \phi_h = 2714 \, \text{W} \]

7. Auswahl des Heizkörpers aus dem Heizkörper-Katalog, \( \Phi_h \) für 75/65:

- Gewählt: 2000/500 Typ 21
\[ \phi_{h,\text{eff}} = 2400 \, \text{W} \]

- Verhältnis der Wärmeleistung \( \Phi / \phi_{h,\text{eff}} \)
\[ \frac{\Phi}{\phi_{h,\text{eff}}} = \frac{760}{2400} \]
\[ \frac{\Phi}{\phi_{h,\text{eff}}} = 0.317 \]

Bei \( \Delta T_1 = 23 \, \text{K} \) wäre \( \Delta T_2 = 18.5 \, \text{K} \) und \( \sigma = 4.5 \, \text{K} < \sigma_{\text{min}} \)

3. Design difference between inlet and outlet water temperatures:

- from Figure C2
\[ \sigma_{\text{And}} = 7.5 \, \text{K} \]

4. Inlet water excess temperature as per Equation (10):
\[
\Delta T_{1,\text{pl}} = \Delta T_{1,\text{max}} + \frac{\sigma_{\text{And}}}{2}
\]
\[ \Delta T_{1,\text{pl}} = 22.05 \, \text{K} \]
da \[ t_{1,\text{min}} = 45 \, ^{\circ}\text{C} \]
\[ \Delta T_{1,\text{pl}} = 55 \, ^{\circ}\text{C} - 22 \, ^{\circ}\text{C} \]
\[ \Delta T_{1,\text{pl}} = 23 \, \text{K} \]

5. Outlet water excess temperature as per Equation (11):
\[
\Delta T_{2,\text{pl}} = \Delta T_{1,\text{pl}} - \sigma_{\text{And}}
\]
\[ \Delta T_{2,\text{pl}} = 23 \, \text{K} - 7.5 \, \text{K} \]
\[ \Delta T_{2,\text{pl}} = 15.5 \, \text{K} \]

6. Determination of standard thermal output

- from heating-appliance design diagram Figure C3
\[ \Phi / \phi_h = 0.28 \]
- standard thermal output as per Equation (12):
\[
\phi_h = \frac{Q_d}{\phi_{h,\text{eff}}}
\]
\[ \phi_h = 2714 \, \text{W} \]

7. Selection of heating appliance from heating-appliance catalogue, \( \phi_h \) for 75/65:

- selected: 2000/500, type 21
\[ \phi_{h,\text{eff}} = 2400 \, \text{W} \]
- ratio of thermal outputs \( \Phi / \phi_{h,\text{eff}} \)
\[ \frac{\Phi}{\phi_{h,\text{eff}}} = \frac{760}{2400} \]
\[ \frac{\Phi}{\phi_{h,\text{eff}}} = 0.317 \]

\( \Delta T_1 = 23 \, \text{K} \) would result in \( \Delta T_2 = 18.5 \, \text{K} \), and \( \sigma = 4.5 \, \text{K} < \sigma_{\text{min}} \)
8. Anheben der Vorlaufentemperaturen wegen \( \Delta T_1 = 25 \, \text{K} \)

9. Rücklaufentemperatur für Heizkörper bei \( \phi / \phi_{\text{st}} \)
   - aus Heizkörperauslegungsdiagramm Bild C3
     \( \Delta T_{2,\text{st}} = 17 \, \text{K} \)
   - Rücklaufentemperatur
     \( t_2 = \Delta T_{2,\text{st}} + \delta_A \)
     \( t_2 = 39 \, ^\circ\text{C} \)

10. Wasserstrom für \( \sigma_{\text{stab}} \) nach Gl.(14)
    \( \dot{\gamma}_w = 0,0227 \, \text{kg/s} \)
    \( \dot{\gamma}_w = 81,82 \, \text{kg/h} \)

11. Überprüfung der Ergebnisse
    - Raumheizflächen-Ubertemperatur nach Gl.(13)
      \( \Delta T_{3, \text{st}} = \frac{\Delta T_1 + \Delta T_{2,\text{st}}}{2} = \Delta T_{3,\text{H}} \)
      \( \Delta T_{3,\text{H}} = 21 \, \text{K} > 18,3 \, \text{K} \) Gl.(13) erfüllt

12. Überprüfung der Aufheizreserve
    Annahmen: Vorlaufentemperaturanhebung zu Aufheizzwecken auf \( t_i = 65 \, ^\circ\text{C} \), keine Anhebung des Massenstroms (\( \dot{\gamma}_w = \text{const.} \))
    - aus Heizkörperdiagramm Bild C3
      \( \phi_{\text{max}} / \phi_{\text{st}} = 0,62 \)
      \( \phi_{\text{max}} = 1488 \, \text{W} \)
      \( \Delta \phi_{\text{H},\text{st}} = \phi_{\text{max}} - \phi_{\text{st}} \)
      \( = 1488 \, \text{W} - 760 \, \text{W} = 728 \, \text{W} > \phi_{\text{H},\text{st}} \)
      Aufheizreserve durch Betriebsheizfläche ausreichend!

8. Increase of inlet water temperature because of \( \sigma_{\text{stab}} \), \( \Delta T_1 = 25 \, \text{K} \)

9. Outlet water temperature for heating appliance at \( \phi / \phi_{\text{st}} \)
   - from heating-appliance design diagram
     Figure C3
     \( \Delta T_{2,\text{st}} = 17 \, \text{K} \)
     - outlet water temperature
     \( t_2 = \Delta T_{2,\text{st}} + \delta_A \)
     \( t_2 = 39 \, ^\circ\text{C} \)

10. Water flow rate for \( \sigma_{\text{stab}} \) as per Equation (14)
    \( \dot{\gamma}_w = 0,0227 \, \text{kg/s} \)
    \( \dot{\gamma}_w = 81,82 \, \text{kg/h} \)

11. Check of results
    - heating-surface excess temperature as per Equation (13)
      \( \Delta T_{3, \text{st}} = \frac{\Delta T_1 + \Delta T_{2,\text{st}}}{2} = \Delta T_{3,\text{H}} \)
      \( \Delta T_{3,\text{H}} = 21 \, \text{K} > 18,3 \, \text{K} \) fulfills Equation (13)

12. Check of heating-up reserve
    Assumptions: Increase of inlet water temperature to \( t_i = 65 \, ^\circ\text{C} \) for the purpose of heating up, no increase in mass flow (\( \dot{\gamma}_w = \text{const.} \))
    - from heating-appliance design diagram
      Figure C3
      \( \phi_{\text{max}} / \phi_{\text{st}} = 0,62 \)
      \( \phi_{\text{max}} = 1488 \, \text{W} \)
      \( \Delta \phi_{\text{H},\text{st}} = \phi_{\text{max}} - \phi_{\text{st}} \)
      \( = 1488 \, \text{W} - 760 \, \text{W} = 728 \, \text{W} > \phi_{\text{H},\text{st}} \)
      => sufficient heating-up reserve provided by normal-duty heating surface!
An energy and process optimization assessment (EPOA) study was conducted at selected U.S. Army installations in Germany and at two U.S. Army Garrison Wiesbaden schools to identify potential for energy conservation at those locations. The study identified energy conservation, process optimization, and environmental improvement opportunities that could significantly reduce operating costs and improve the installations’ mission readiness and competitive position. Eighty-five energy conservation measures (ECMS) were identified, most of which were quantified economically; if implemented, these ECMS would reduce annual electrical energy consumption by approximately 24,121 MWH, thermal heating consumption by 17,277 MWH, and total operating costs by approximately $1.4 million/yr. Implementation of all these ECMS would cost approximately $9.7 million and would yield an average simple payback of 7.2 yrs. The study recommends that these potential cost savings be aggressively pursued with an program of energy and process optimization. A separate level I EPOA study of the industrial complex at the Germersheim DDDE and a Level II EPOA study at the flight simulator building in Illesheim were also recommended, since these locations both show potential for significant reductions in energy use and operating cost, and for improvement in worker productivity.