<u>Mechanical Insulation System Study</u>

Mechanical Insulation Systems are neglected and overlooked in most facilities and buildings in America. Properly installed and maintained mechanical insulation systems can save millions of dollars in fuel costs, improve facility comfort, accentuate market competitiveness, and improve indoor air quality.

Engineers, architects, and facility owners are unaware of the immense costs and system efficiency improvements realized with professionally installed, maintained, and upgraded mechanical insulation systems. An independent, third-party inspection of a facility's existing mechanical insulation systems will evaluate their performance, provide tangible visual images of energy loss, and verify potential cost, energy, and environmental savings for all stakeholders.

Mechanical Insulation encompasses thermal, acoustical, life safety, and personnel requirements in buildings with commercial and industrial applications. There are no National Standards, National Codes, Universal Energy Policies, or National Best Design Practices related to mechanical insulation. Therefore, each facility owner, mechanical engineer, and architect must become educated concerning the function and interrelationship between mechanical insulation and the cost of operating a facility, whether it is a commercial building or an industrial facility.
To assist with the education process, we provide the following insulation study performed on two prominent commercial facilities in Houston, Texas.

Many of the issues and conditions contained in the enclosed report are indicative of problems that are common throughout facilities in North America.

This report concerns the performance of the Mechanical Insulation Systems (MIS) on the Chilled Water, Heating Hot Water, Domestic Hot Water & Domestic Cold-Water piping & associated equipment, as well as the Supply, Return, and Kitchen Exhaust Insulation Systems, at two Houston, Texas Sports Complexes, in Houston, Texas. Specifically assessed and identified were system components that were not insulated or had significantly damaged and missing insulation. These included systems insulated with fiberglass, elastomeric foam, cellular glass insulation (foamglas®), and inorganic fiber blanket encapsulated with a scrim-reinforced foil.

Our evaluation determined that significant process improvement opportunities exist, even though the MIS's are well-maintained for the age of these systems. In particular, the continued maintenance/ improvement of the MIS will provide an exceptional Return on Investment (ROI) for implementation and a plethora of additional benefits. The potential for Improved Indoor Air Quality (IAQ), cannot be overstated. Many do not realize the effect of inhalation of mold spores and associated mycotoxins on the human body, including respiratory issues, fatigue, muscle aches, and reduced exercise tolerance due to the inflammatory response triggered by these agents.

The energy savings and emission reduction opportunity is significant, as the enclosed chart exhibits. Our calculations of the MIS yielded reductions in energy usage and environmental impacts. This chart presents written engineered calculations of energy losses that pertain to systems that did not have the proper Mechanical Insulation applied, or mechanical insulation was missing or not maintained.

For the MIS at the Houston, Texas facilities, the paybacks would be as follows:

Item	Amount
Inspected Piping (actual)	5500‘
Missing Pipe Insulation (22.2%)	1221’
Cost of Missing Insulation	$19,356.62
Cost of missing Insulation per foot	$15.85
Total Facility Piping (estimated)	44,847
Missing Pipe Insulation (21.66%)	9,714.94
Lost Energy Cost of missing mechanical insulation extrapolated (estimated)	$153,981.79
CO_2 Reduction (Actual) lbs/ft/yr	293.337
CO_2 Reduction (Estimated) lbs/ft/yr Based on extrapolated calculations	1,473,354
CO_2 MT Reduction (Actual) lbs/ft/yr	132.24
CO_2 MT Reduction (Estimate) lbs/ft/yr Based on extrapolated calculations	619.37
NO_X Reduction (Actual) lbs/ft/yr	603.64
NO_X Reduction (Estimated) lbs/ft/yr Based on extrapolated calculations	3,036.24
K Btus Saved (Actual)	1,639,346.3
K Btus Saved (Estimated) Based on extrapolated calculations	45,857,045

The data in the previous table is based on our field observations/ site survey, available drawings, and other information available to our team. We calculated the quantities of each insulation system and the estimated BTUs and dollar cost of:
a) Operating the systems in their current conditions, and,
b) Operating the systems after installation of the appropriate type and thickness of mechanical insulation.

We included calculations of the emission savings associated with the recommended upgrades. We used the 3E Plus® program to perform our calculations. The 3E Plus® program was initially developed under a contract from the Federal Energy Administration (FEA), Office of Industrial Programs.

Clarifications

The information provided in this report does not include any allowance for incentives for energy or emission reductions. The following advantages of upgrading your mechanical insulation systems should be considered:

Reduced Energy Consumption

Control of Mold and Mildew

Enhanced Budgeting through Lower Energy Costs & Consistent Future Energy Cost Quantification

Improved Facility Life-Cycle Costs

Exceptional Return On Investment (ROI) for Maintaining and Updating the Mechanical Insulation Systems

Reduced Operating Expenditures

Reduced “Corrosion Under Insulation” (CUI)

Enhanced Personnel Protection, Noise Control, and Fire Safety

Potential Tax Benefits and Credits from Energy Conservation Investments

Improved Indoor Air Quality

Improved Process Flows

Extended Equipment Service Life

Condensation Control and Prevention

Freeze Protection

More Attractive & Comfortable Working Environments

The preceding information does not include available incentive cost savings/ tax incentives for extended equipment life or for improving energy efficiencies and emission reductions. The quantification of savings is based on “Simple Payback Calculations”.

Mechanical insulation is designed to maintain the system's temperature from one location to another with as little fluctuation of energy flow as possible or practical. Hot systems should remain hot, and cold systems should remain cold, with minimal temperature change and as little energy loss or gain as practical. Reducing temperature variability allows the system to operate as close to the designed engineered conditions as possible while greatly extending the service life of the equipment.

The design of MIS must utilize numerous criteria, including the temperature of the system, mechanical processes, the flow from the generation of applicable system temperatures to the point at which work/ processes are performed, personnel safety, engineering design temperatures, anticipated future energy costs, and ambient wind speeds. We have evaluated the MIS included in this report and have used our extensive expertise and engineering judgements, in conjunction with the available site-specific data, to determine the best materials, application techniques, system design parameters, available site-specific engineering and cost measures to provide the best ROI, while delivering the intended engineering design goals. We have considered the intended system usage and have tried to minimize the temperature variations of process temperatures to minimize energy use. As part of our evaluation of the MIS, we have encompassed the principles and associated equations listed below.

Recommendations
Based on the review of the conditions of the existing Mechanical Insulation Systems, moving forward, we recommend the following:

1. Hiring or intense training of “in-house” individuals to be the “resident”, Subject Matter Expert (SME), to inspect any MIS installations or repairs.

2. Identify, prioritize, and install MIS repairs on all missing mechanical insulation, system piping, ductwork, and equipment.

3. Immediately begin documenting, including infrared images of the condition, repairs & replacement of any work on the MIS. (This will reduce the likelihood of future adverse publicity or judgments against ownership/ management.)

4. Review and revise the Mechanical Insulation System Specifications (MISS) to update materials, installation processes, and inspections, including a post-inspection of completed repairs & installations to confirm proper system installations. This should include verification and documentation by a Subject Matter Expert (SME). Proper installation of Vapor Stops on Chilled Water (CHW) systems to reduce mold growth, vibration degradation of cellular glass products, etc. Included in revised specifications should be verifications, including “C of C” (Certification of Conformance) with Vapor Barrier, as well as mastics for Chilled Water system (CHW), purchases of materials & verification through continuous inspections of installation processes.

   Updated specifications should include increased efficiencies to reflect anticipated fuel cost increases in mechanical system efficiencies (including any reductions in temperature or flow changes of CWS and potential future facility uses).

   Specifications should be reviewed for possible revisions every five years to account for changes in technologies, mechanical systems, facility uses, etc.

5. Develop an inspection plan, verify it, create a checklist, and document MIS. Inspections should be conducted annually at a minimum and anytime mechanical systems or components are repaired or upgraded.

6. Develop a plan with anticipated mechanical system replacements and upgrades to improve efficiencies and reduce interferences, such as improved hangers and reductions or elimination of Victaulic piping (critical on CHW systems).

7. If a chilled water system plant is constructed and utilized for the facility, the entire chilled water system should be inspected and likely upgraded to account for the upgrades in these systems, including changes in chilled water temperatures, process flows, and mechanical system efficiencies.

8. The heating system's mechanical insulation should be inspected and upgraded to account for fuel cost increases since the initial facility construction. Upgrades, including any specification insulation thickness increases, should be based on anticipated fuel escalation. These evaluations should include any climatic changes to area temperatures, based on area bin

tables. (Changes may result from surrounding building construction/ changes, increased population densities, "central city heat sink changes", etc.)

9. Review using MIS as an Asset versus an Expense. MIS is a valuable resource that will provide future benefits to the facility. As such, it should be classified as an asset. It should be inspected, maintained, and/ or upgraded as an asset to ensure the best performance of the associated mechanical systems. Optimized MIS extends the lifespan of associated mechanical systems, improves their performance, and helps provide the facility with the best possible indoor air quality.

10. Review and revise the Firestop System Specifications to update materials, installation processes, and inspections, including a post inspection of completed assemblies, repairs & installations, including verification & documentation with a Firestop Subject Matter Expert (SME). All Firestop System Installations should be contracted to a certified, qualified installation contractor. All installations should be performed by a qualified, certified Firestop installation professional with at least five years of experience. Specifications should include verification, including "C of C" (Certification of Conformance) for materials, installations & labeling of fire-stopped penetrations.

    The Mechanical Insulation Specifications and the Through-Wall Firestop Specifications should be reviewed to ensure they are compatible.

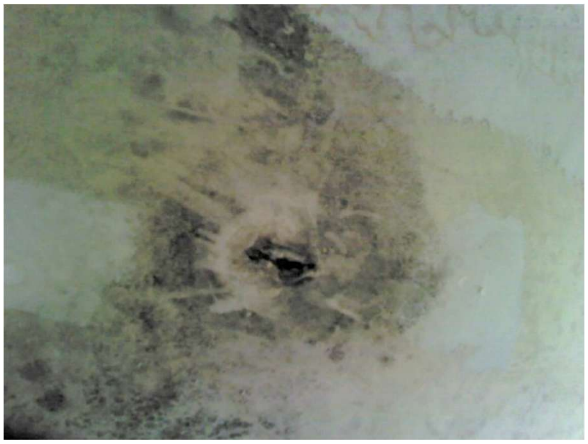
Corroborative Case Studies Specific to Houston Entertainment Facilities

Pertaining to Specifications

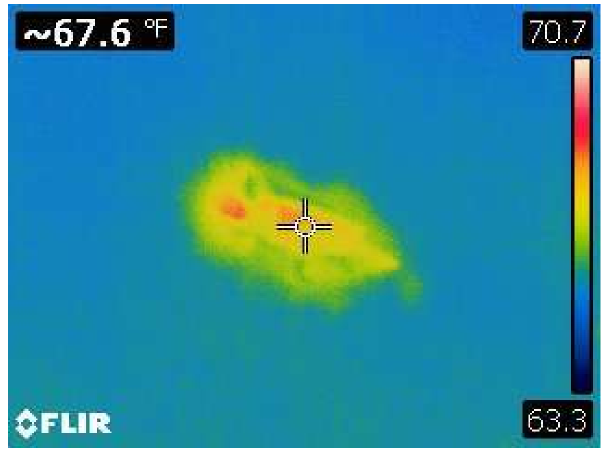
1. Observations
2. Potential Explanations
3. Conclusions

The following cases are only based on what was observed and collected during the walk-through of the South Texas Entertainment facilities. We could not access a copy of the facilities' entire Mechanical Insulation Specification. Therefore, our observations are based on manufacturers' recommended installation procedures and industry standards.

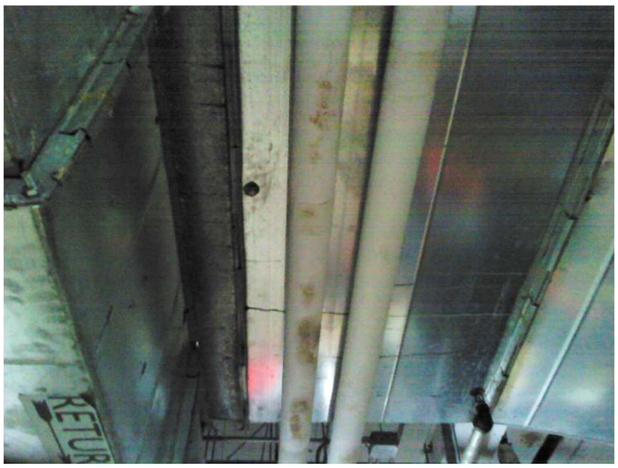
A more in-depth investigation can be conducted, but that would require a more historical investigation of the installation and maintenance of the mechanical insulation systems and the removal and reinstallation of some of the mechanical insulation to allow under-insulation inspections. For example, the pipe must be exposed to determine the amount of Corrosion Under the Insulation (CUI).



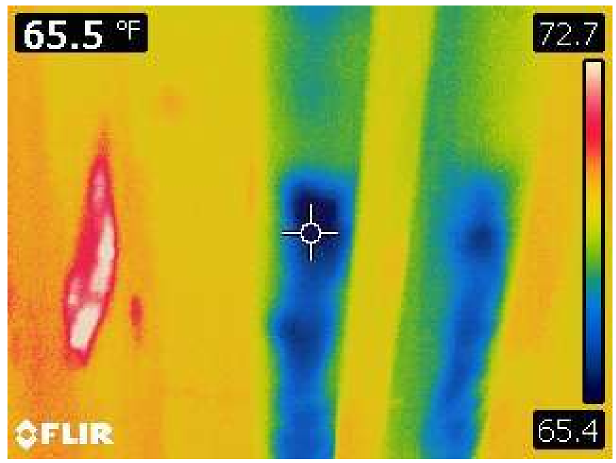
Black Mold on Ceiling in Hallway



Infrared Image of Black Mold on Ceiling in Hallway



Piping insulation with mold growth due to moisture



Infrared Image of Piping insulation with mold growth due to moisture

Case # 1 – Black Mold on Insulation

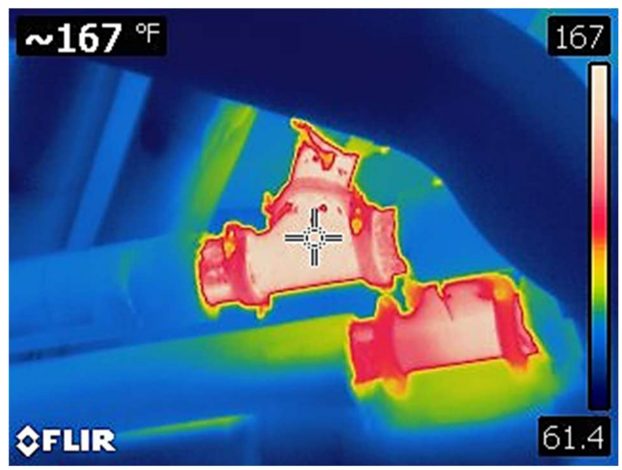
1. **Observations –** Suspected presence of black mold. Stachybotrys Chartarum is a toxic fungus found in many chilled water insulation applications. Testing would be required to confirm the type of perceived fungal growth observed. Typically, the conditions promoting this growth are caused by moisture entering and migrating within the insulation in below-ambient applications. The cool temperatures recorded by the thermal images captured during our facility walk-through show evidence of these conditions. Although not determined because no insulation was removed, these conditions often lead to CUI.

2. **Potential Explanation –** Vapor barriers or vapor retarders on the insulation were not sufficient to prevent condensation. Vapor barriers must be installed on any mechanical insulation on chilled water or below ambient applications to prevent moisture from entering the insulation. The prevention of moisture infiltration can be accomplished by selecting the proper vapor barrier materials and using the correct installation workmanship techniques to apply these vapor barriers. (1) In this particular case, it appears there was a lack of utilization of proper vapor barriers under the PVC fittings. The “All Service Jacket” (ASJ), used on most of the chilled water system insulation, typically presents a weak point in vapor transmission, especially in chilled water applications. (ASJ is typically made from a combination of fiberglass and aluminum foil. The fiberglass provides thermal insulation and

shear strength. The aluminum foil provides a vapor barrier and helps to reflect radiant heat.) (2) Houston Sports Authority should recommend that the installer have at least 5 years of experience installing mechanical insulation on chilled water systems. Without performing some insulation removal to identify a workmanship issue and without knowing the installer's experience, the lack of consistent vapor barrier protection is usually related to poor workmanship when rapid installation has priority over quality.

3. **Conclusions -** It is reasonably concluded that if all systems had proper vapor barriers and vapor stops were adequately applied with proper PVC jacketing instead of ASJ. If normal industry standards had been followed and the installer had the appropriate experience to realize the importance of such applications, the presence of black mold, apparently Stachybotrys Chartarum, could have been avoided. In addition, the risk of CUI would be significantly reduced. Following the insulation manufacturers' recommended engineering requirements will offer superior results. At the same time, “value engineering” /changes to mechanical insulation usually lead to the inferior performance of the systems and increased energy and life cycle costs, negating any initial savings.

Missing Heating Hot Water Insulation



Infrared Image Missing Heating Hot Water Insulation

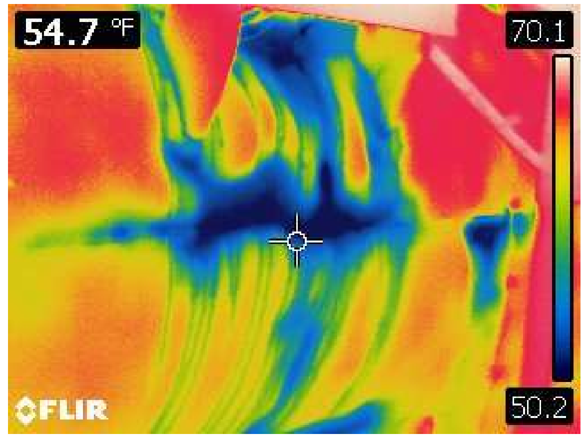
Case # 2 – Inspection procedures

1. **Observations –** Some areas appeared inadequately maintained and improperly re-insulated, as evidenced by moisture accumulation or lack of insulation in various places.

2. **Potential Explanations—**Lack of educated inspectors or failure to recognize normal accepted industry standards and manufacturers' procedural installation requirements.

3. **Conclusions—**If the installation/ material compromises had been adequately recognized and the manufacturers' procedural installation requirements had been utilized, many, if not all, of these deficiencies could have been avoided. Mechanical insulation requires a regularly performed, routine inspection to identify where it needs to be repaired, replaced, or properly maintained.

Compromised Elastomeric Foam Insulation



Infrared Image of Compromised Elastomeric Foam Insulation

Case # 3 – Elastomeric Foam Insulation (Armaflex)

1. **Observations –** The Elastomeric Foam insulation on the chillers showed evidence of degradation, compromising the insulation's thermal performance. This leads to moisture accumulation under the insulation and reduced thermal performance, preventing the system from operating as effectively as designed.

2. **Potential Explanations** - (1) **UV Radiation:** UV radiation, a form of electromagnetic energy, can cause chemical reactions in materials, including plastics and rubbers. Outdoors, the Sun emits radiation in the form of UVA, UVB, and UVC rays. Indoors, UV radiation is emitted by all lamps, including quartz halogen, tube fluorescent, compact fluorescent, tungsten, and filament incandescent. (2) **Photochemical Reactions:** These reactions break down the long chains of molecules that comprise the material's structure. Either of the listed scenarios will cause the insulation material to become less flexible and brittle. The weakened insulation structure reduces the materials' capability to withstand stress, causing cracking and crumbling while increasing the vapor permeability of the insulation.

3. **Conclusions—**This insulation should be replaced and either covered with a jacketing material such as PVC or coated with a product such as ArmaFlex WB Finish, a white, water-based, 100% acrylic coating for use over all forms of Elastomeric Foam insulation. ArmaFlex WB Finish is resistant to UV radiation and ozone and is weather resistant and durable. This paintable coating is engineered to dry without emitting fumes, with cold-weather flexibility as it resists cracking. It provides a clean, moisture-resistant protective finish suitable for indoor and outdoor applications. However, outdoor surfaces should be recoated every 2 to 4 years for best results.

Missing Insulation with Significant Heat Loss

Infrared Image of Missing Insulation with Significant Heat Loss

Case # 4 – Lack of Insulation causes heat loss/gain.

1. **Observations –** through digital imaging and infrared thermography, there was some missing mechanical insulation; it was apparently removed for maintenance/ repair activities, resulting in energy losses. Our initial MIS review did not sanction an investigation of the insulation through the removal & inspection of existing MIS to confirm adherence to specified material types, correct material thickness, and installation procedures per the manufacturer's installation requirements.

2. **Potential Explanations—**Missing insulation can result from maintenance activities, physical abuse, facility activities, improper initial installations, moisture degradation, system changes, etc. The higher temperatures of exposed heated piping will increase the cost of maintaining conditioned spaces. The additional heating of ambient air increases air convection, contributing to inefficiencies in the chilled water systems and the system's cooling capabilities.

3. **Conclusions—**The mechanical system design engineers and architects must maintain the MIS Installation, comply with the manufacturer's recommended guidelines, adhere to the facility's mechanical system specifications, and confirm installation instructions to achieve engineered outcomes. The ROI for repairing or replacing missing mechanical insulation is typically less than two years for piping, ductwork, and equipment.

Improper Support with Compromised Insulation

Infrared Image of Improper Support with Compromised Insulation

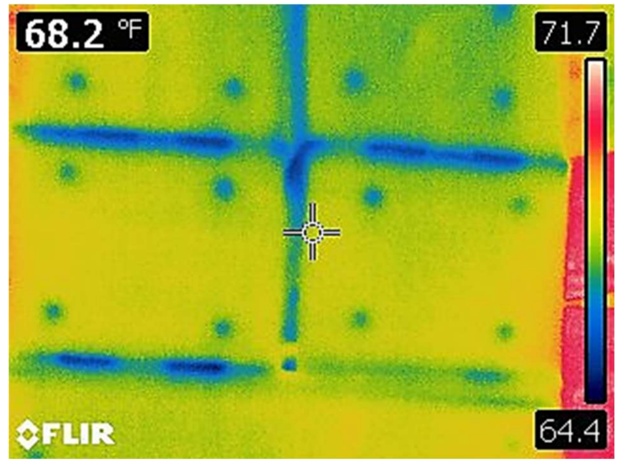
Case # 5 – Pipe Supports and Hangers

4. **Observations-** per the following images, hanger insulation did not utilize proper thickness/ supports. The image demonstrates significant heat loss as the red color indicates approximately 118°F on this hanger. This hanger support should allow movement. From the image, the system does not appear to have an insulation support properly inserted/ or a hanger appropriately sized, allowing proper system function and support. These conditions cause undue stress on mechanical system components, leading to premature device/ system failures.

2. **Potential Explanations**- (1) The piping installer did not insert the proper piping supports. (2) It is possible that the unit's temperature is much higher than shown, with a temperature differential of 193° F (∆t). (3) It is also possible that the hanger itself is too small for this application; a hanger or a “hanger shoe” that is more extensive and welded to the pipe will provide enough support and insulation thickness to the adjacent piping insulation.

3. **Conclusions—**The heat application support system specification not obtained for this particular hanger would indicate the proper sizing of the hanger. Regardless of the type of hanger, the correct hanger size must be used to provide the correct amount of insulation thickness and system support.

Insulated Ductwork in Mechanical Room



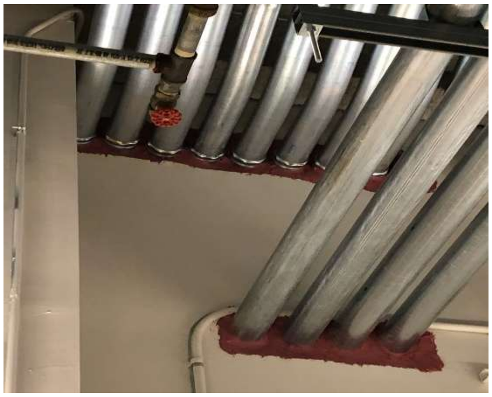
Infrared Image of Insulated Ductwork in Mechanical Room

Case # 6 – Ductwork

1. **Observations –** We observed moisture in the duct insulation, similar to the chilled water piping system applications. There were no visible signs of mold, but usually, there may be mold within this insulation system, which may not be easily visible on the foil exterior finish. It is safe to assume that if moisture is present in the fibrous insulation, there is a likely chance that some mold will be present. It also appears that there is compromised insulation thickness at the duct reinforcement flanges. This leads to moisture and/ or condensation, often initially on the outside. As the thermal efficiencies of the insulation are compromised through moisture infiltration, the MIS interior allows for mold growth with CUI, attacking the metal surfaces.

2. **Potential Explanations—**Any moisture in the insulation is usually a direct result of a lack of a Vapor Barrier or Vapor Retarder being properly sealed. (Foil-Scrim-Kraft (FSK) facing is a flame retardant, vapor-barrier jacket on most duct insulation systems. FSK facing is manufactured from a thin layer of lightweight aluminum foil layered against a tri-directional, reinforcing fiberglass scrim (yarn) and then paired with a final layer of natural brown kraft paper. All layers are laminated together using a flame-retardant adhesive.) FSK requires completely 100% sealed joints, using pressure-sensitive sealing tapes to prevent moisture infiltration and migration. If the duct is in an area where common physical contact is possible, abuse of the FSK could compromise the system.

3. **Conclusions—**We do not have ductwork insulation specifications. The installation requirements would be similar to those in case #1—to follow the manufacturer's recommended installation procedures and have installers knowledgeable and well-experienced in vapor barrier protection.



Firestopped Conduit in Wall

Firestopped Conduit in Floor

Case # 7 – Firestop Penetrations

1. **Observations –** We did not examine any firestop systems other than a walk-by glance. However, there is a concern that the firestop systems were not labeled. Therefore, it cannot be determined if the correct firestop application was applied.

2. **Potential Explanations –** Often, changes are made with materials that are not inclusive to account for all considerations throughout the specifications.

3. **Conclusions—**Without specifications for review that are precise about the installer's qualifications, we cannot determine if the correct firestop installation was made. A certified and trained person should be required to install the firestop system. The qualifying person will ensure the proper system is utilized at the time the system is installed. There are too many variables for the firestop systems to list until the actual penetration is executed.

Executive Summary Conclusions / Priorities

The evaluation determined that the MIS's condition is better maintained than most systems of their age. We had expected the MIS to be more distressed than what was observed. There are still significant process improvement opportunities in the MIS, which will also improve the HVAC and plumbing systems' performance.

We would first address the missing insulation on the different mechanical systems. As soon as mechanical insulation is applied, these systems will experience an immediate cost reduction.

Due to the significant amount of visible mold contributing to reduced Indoor Air Quality (IAQ), we would develop a plan to begin upgrading and replacing the underperforming chilled water mechanical insulation system. Proper Vapor Barrier installation should be paramount, ensuring this process is properly completed. The specifications for chilled water insulation should be aligned to include language allowing for the manufacturer's recommendations after review by engineering.

Victaulic Insulation Piping is a significant challenge when properly installing MIS on chilled water systems. We urge a comprehensive review of alternatives and suggest disallowing the installation of Victaulic Piping and devices on any Chilled Water system.

We were surprised that many of the observed MIS did not comply with the insulation manufacturers' recommended installation procedures, compromising MIS value and Indoor Air Quality.

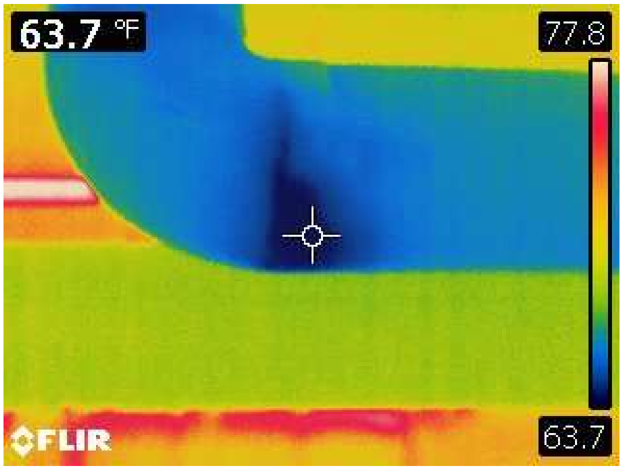
To ensure future compliance, we recommend training for in-house personnel and offer LMCT services to assist with independent third-party evaluation, assurance/ review of new mechanical insulation work, and maintenance. We are available as your Subject Matter Experts concerning the MIS to answer any questions or assist you and your team.

We can better ascertain proper compliance with facility specifications if mechanical insulation specifications are supplied.

The cost of maintenance where mechanical insulation must be removed to allow process changes or to repair equipment, valves, etc., should be assigned to process changes or added to the repair cost of the equipment or system. These costs should not be considered insulation maintenance costs. Over the years, numerous studies have concluded that if mechanical insulation is budgeted at ten percent per year of capital investment, the return on investment of twenty-five to several hundred percent can be assured.

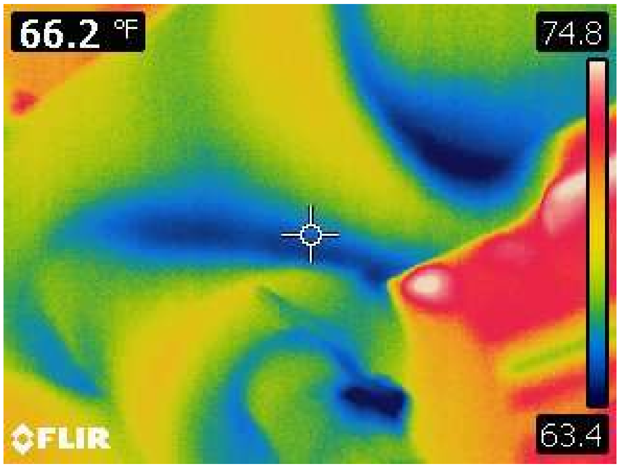
Images of Existing Conditions

Chilled Water Piping with Moisture



Infrared Image of Chilled Water Piping with Moisture

Chilled Water Piping in Mechanical Room

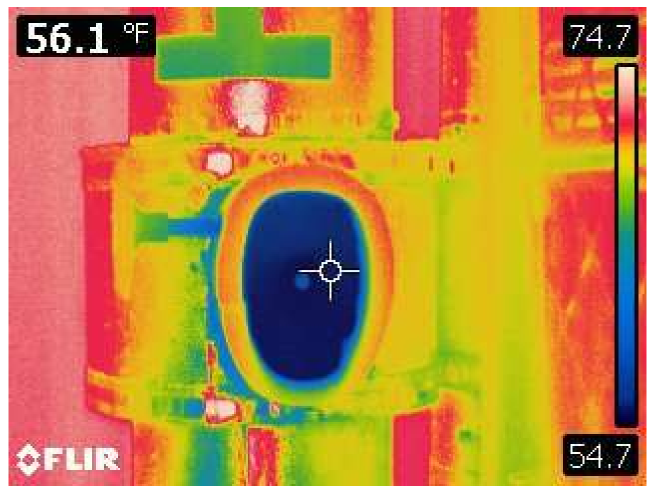


Infrared Image of Chilled Water Piping in Mechanical Room

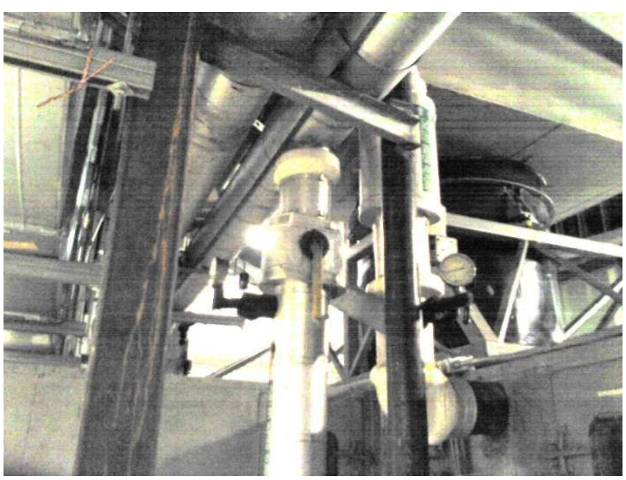
Domestic Hot Water Tanks & Piping

Infrared Image of Domestic Hot Water Tanks & Piping

Inadequate Chilled Water Insulation



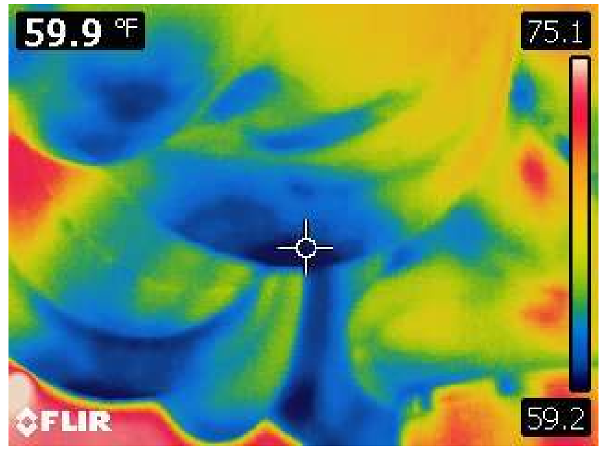
Infrared Image of Inadequate Chilled Water Insulation



Inadequate Chilled Water Insulation, allowing condensation leading to mold growth

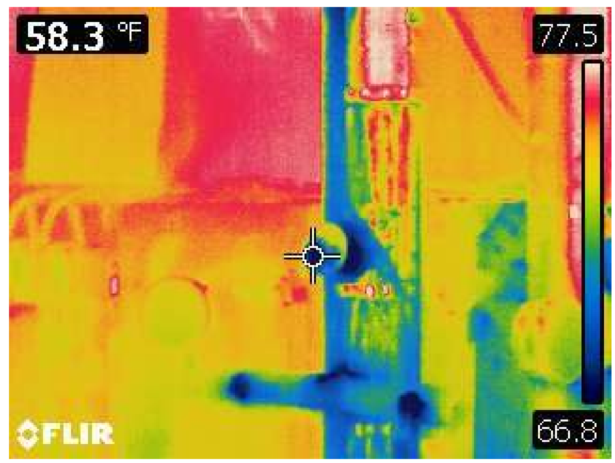
Infrared Image of Inadequate Chilled Water allowing condensation leading to mold growth

Chilled Water Piping without proper vapor barriers, allowing moisture accumulation



Infrared Image of Chilled Water Piping without proper vapor barriers, allowing moisture accumulation

Inadequate Chilled Water Insulation in Insulation allowing moisture condensation



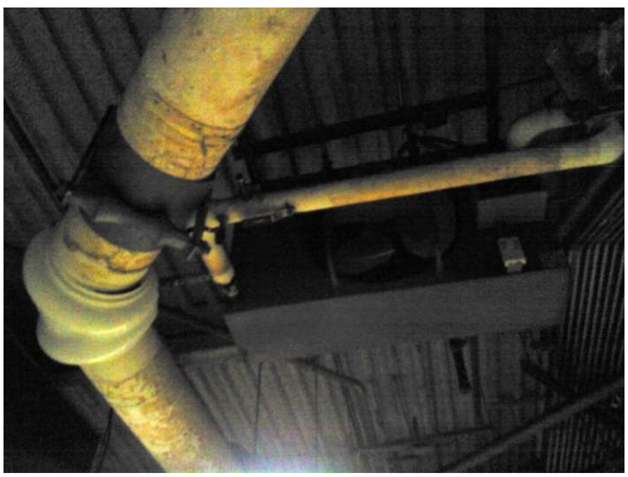
Infrared Image of Inadequate Chilled Water allowing moisture condensation

Uninsulated Hot Water Heating Piping Heating Piping with significant energy loss

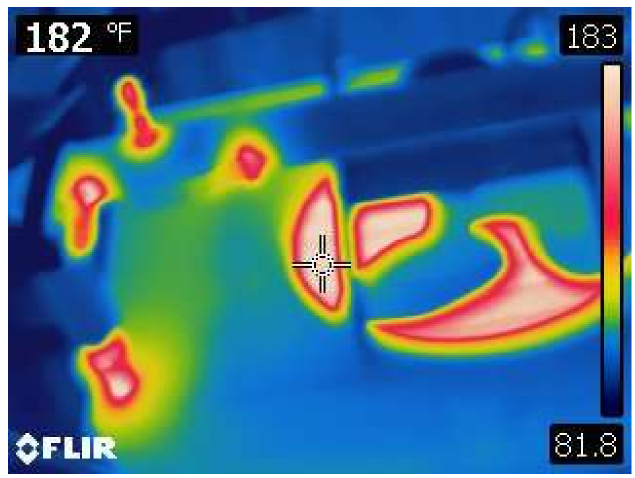
Infrared Image of Uninsulated Hot Water Heating Piping with significant energy loss

Uninsulated Hot Water Heating Piping with Heating Piping with significant energy loss

Infrared Image of Uninsulated Hot Water Heating Piping with significant energy loss



Inadequate Hot Water Heating Insulation Installation Heating with significant energy loss

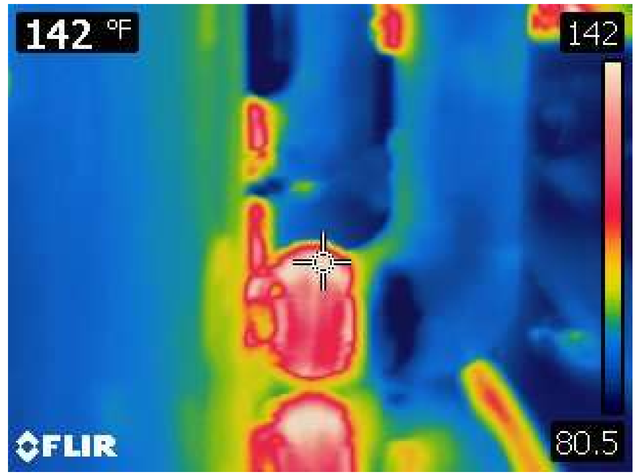


Infrared Image of Inadequate Hot Water Heating, with significant energy loss

Missing Domestic Hot Water Insulation Contributing to fluid temperature drop drop

Infrared Image of Missing Domestic Hot Water Insulation Contributing to fluid temperature

Missing Domestic Hot Water Insulation Insulation



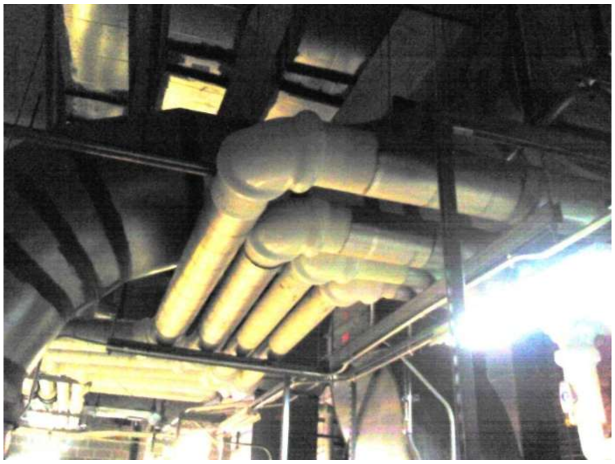
Infrared Image of Missing Domestic Hot Water

Missing Domestic Hot Water Insulation

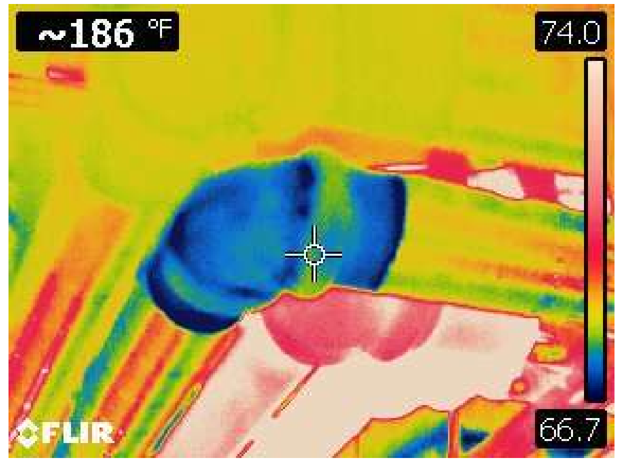
Infrared Image of Missing Domestic Hot Water Insulation

Damaged Hot Water Heating Piping Insulation

Infrared Image of Damaged Hot Water Heating Piping Insulation

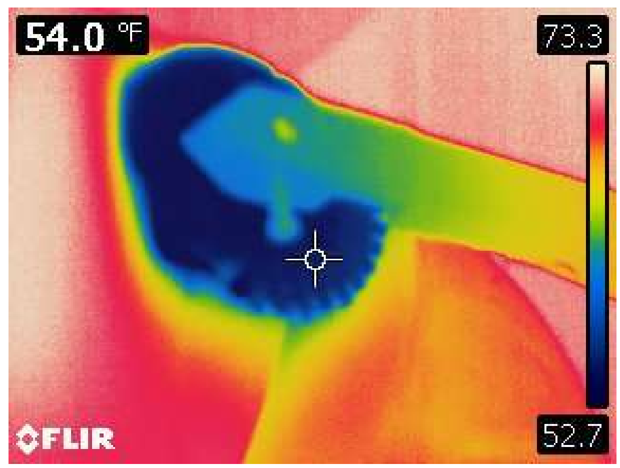


Improperly Installed Hot Water Heating Piping Insulation with significant energy loss



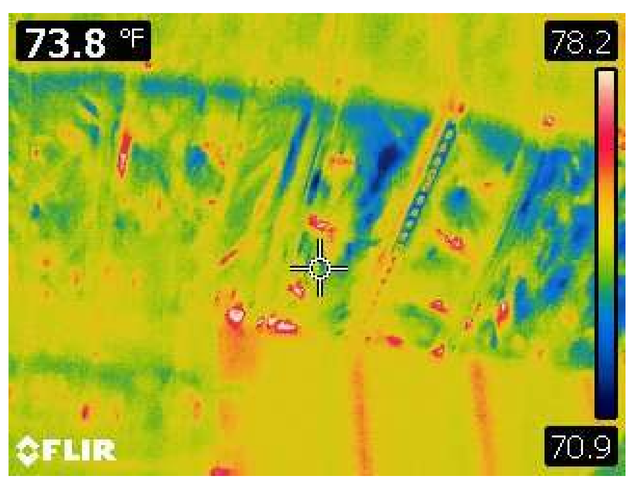
Infrared Image of Improperly Installed Hot Water Heating Piping Insulation with significant energy loss

Chilled Water Butterfly Valve with Condensation

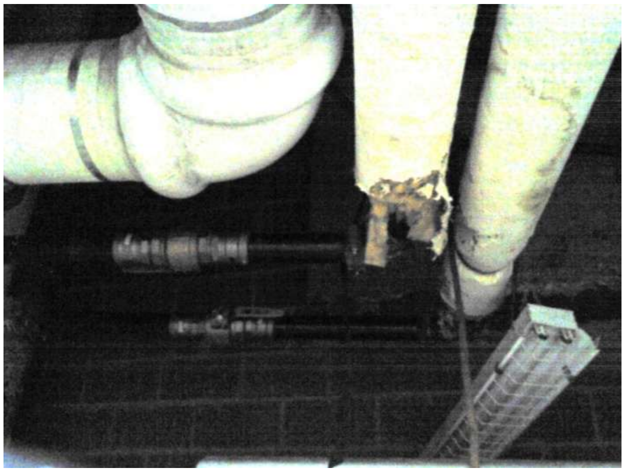


Infrared Image of Chilled Water Butterfly Valve with Condensation

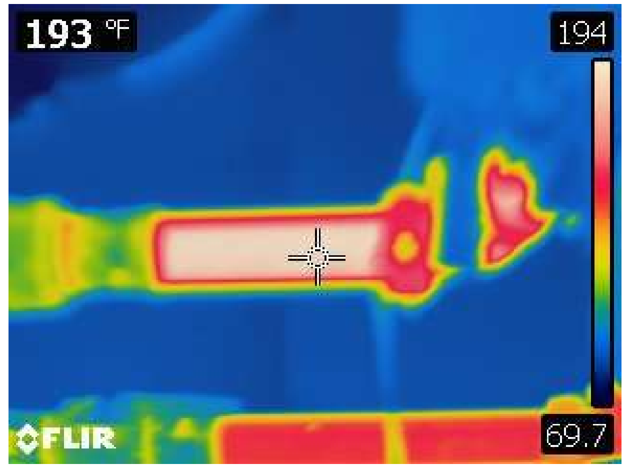
Kitchen Exhaust Fire Protection Insulation –



Infrared Image of Kitchen Exhaust Fire Protection Insulation

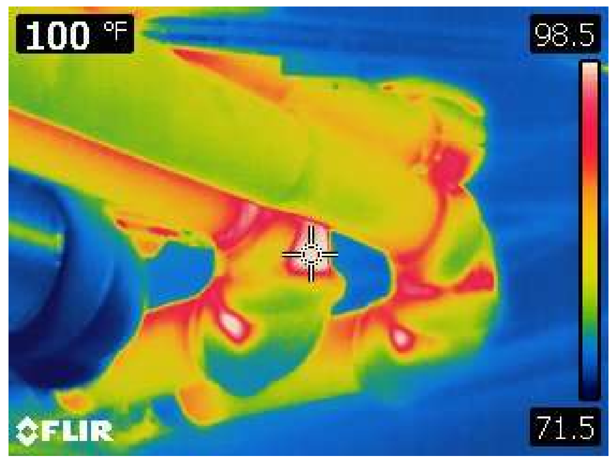


Compromised Insulation due to Improper Support & Missing Insulation

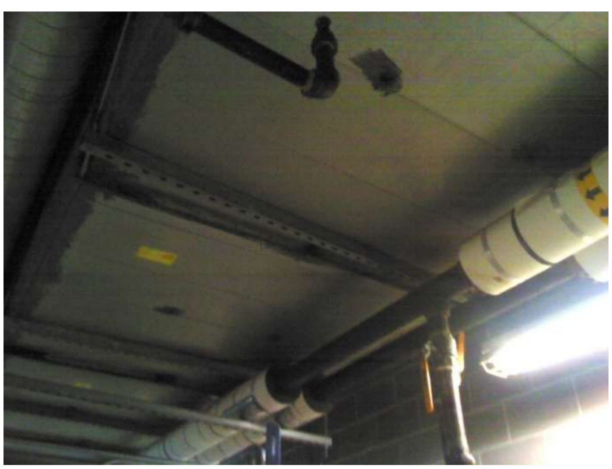


Infrared Image of Compromised Insulation due to Improper Support & Missing Insulation

Improper Thermal Insulation Installation, allowing significant energy loss, due to installation issues



Infrared Image of Improper Thermal Insulation Installation, allowing significant energy loss, due to installation issues



Missing Mechanical Insulation – Potential condensation & Corrosion Under Insulation (CUI)

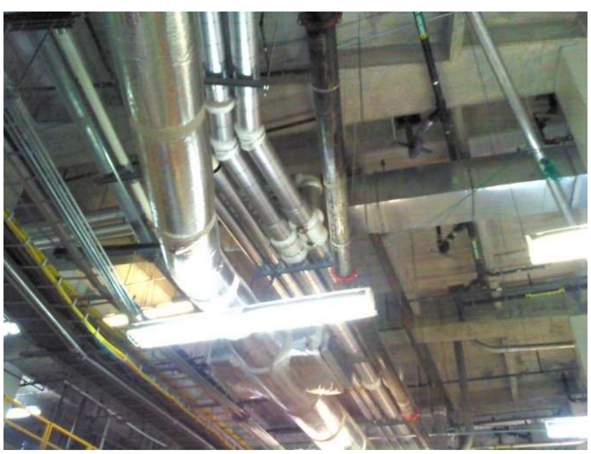
Infrared Image of Missing Mechanical Insulation – Potential condensation & Corrosion Under Insulation (CUI)

Missing Insulation on Food Service Recovery Piping System

Infrared Image of Missing Insulation on Food Service Recovery Piping System

Missing Thermal Insulation, significant energy loss - condensation issue & Corrosion Under Insulation (CUI)

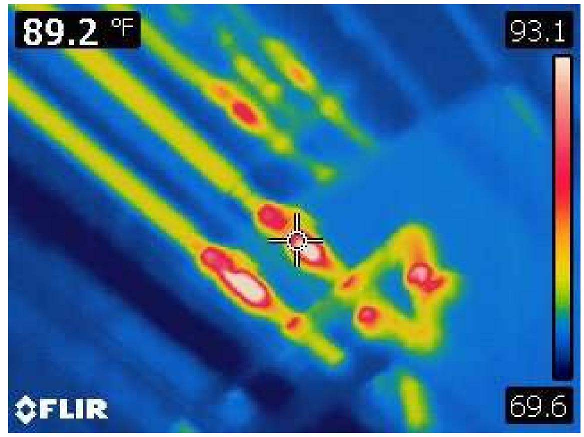
Infrared Image of Missing Thermal Insulation, significant energy loss – condensation issue & Corrosion Under Insulation (CUI)



Improper Insulation Installation, energy loss - condensation issue & Corrosion Under Insulation (CUI)

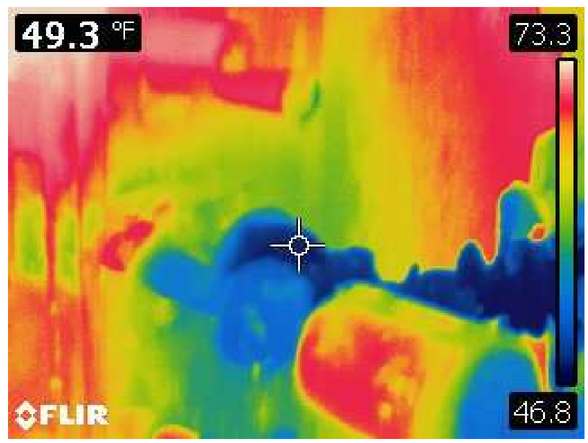
Infrared Image of Improper Insulation Insulation, energy loss – condensation issue & Corrosion Under Insulation (CUI)

Missing Thermal Insulation, allowing significant energy loss



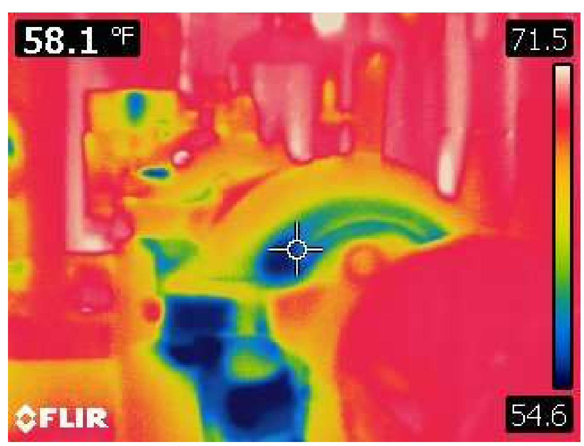
Infrared of Missing Thermal Insulation, allowing significant energy loss

Missing Insulation, significant energy loss – condensation issue & Corrosion Under Insulation (CUI)



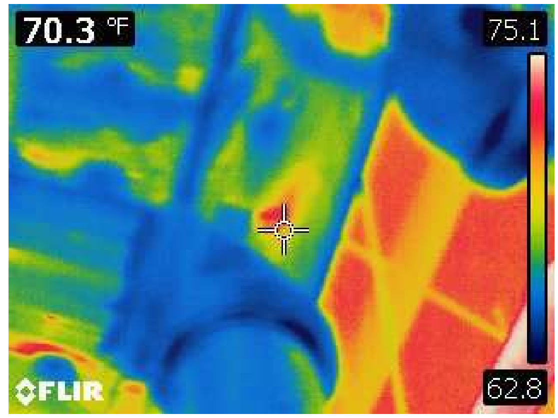
Infrared Image of Missing Insulation, significant energy loss- condensation issue & Corrosion Under Insulation (CUI)

Thermal Insulation Issue, allowing energy loss – condensation issue & Corrosion Under Insulation (CUI)

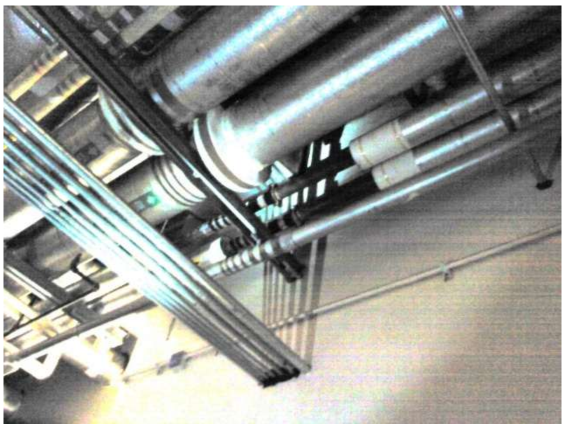


Infrared Image of Thermal Insulation Issue allowing energy loss – condensation issue & Corrosion Under Insulation (CUI)

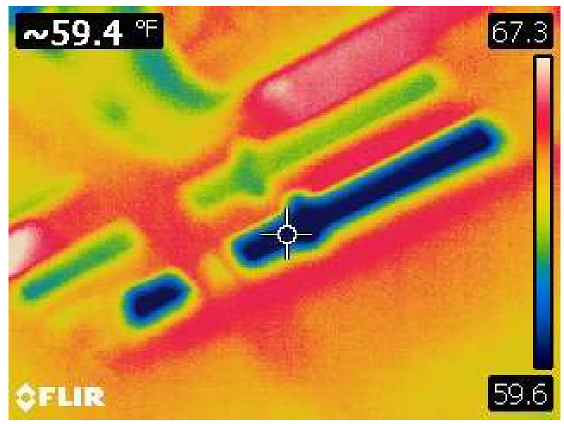
Issues with Ductwork Insulation – Energy Loss



Infrared Images of Issues with Ductwork Insulation – Energy Loss



Missing Thermal Insulation, allowing significant energy loss

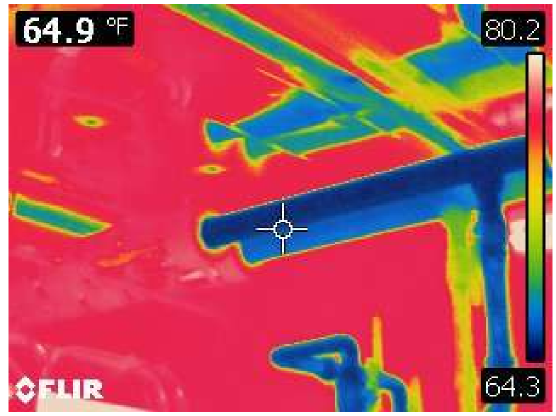


Infrared Image of Missing Thermal Insulation, allowing significant energy loss

Issues with Ductwork Insulation Energy Loss - condensation issue & Corrosion Under Insulation (CUI)

Infrared Images of Issues with Ductwork Insulation – Energy Loss – condensation issue & Corrosion Under Insulation (CUI)

Missing Insulation on Food Service Recovery Piping System



Infrared Image of Missing Insulation on Food Service Recovery Piping System

Indoor Air Quality (IAQ) Issues
Mechanical Insulation is used to help maintain the design temperatures of fluid systems. Indoor Air Quality in occupied buildings is a complex science with many factors affecting the various systems' performance. There is a diversity of human tolerances to different airborne contaminants and the impacts of the various system components. The inhalation of mold spores and mycotoxins may lead to infections, inflammations, gastrointestinal distress, impairment of the respiratory system, and other physiological effects. Obtaining the proper balance between an acceptable IAQ standard and mechanical system performance is challenging. Without a systematic focus on the critical importance of the MIS, there will be deficiencies in the performance of many different mechanical systems.

Relative Humidity Standards
ASHRAE Standard 62.1-2016* recommends controlling relative humidity in occupied spaces to less than 65% to reduce the likelihood of conditions that can lead to microbial growth.
When the Mechanical Insulation on the Chilled Water System contains any deficiencies in performance, the entire system's effectiveness is compromised. This means that the Air Handler Units may not function as originally designed, reducing cooling performance or allowing humid air infiltration to condense on cooler surfaces, resulting in water accumulation and mold growth.

If the chilled water or supply air temperatures rise, the HVAC system's dehumidification capacity is reduced, increasing the moisture load within the building. Continual operation in this mode will result in condensation on cooler systems and widespread surface mold growth.

In the ASHRAE Standard 62.1-2019 version, Buildings or spaces equipped with or served by mechanical cooling equipment shall be provided with dehumidification components and controls that limit the indoor humidity to a maximum dew point of 60°F (15°C) during both occupied and unoccupied hours whenever the outdoor air dew point is above 60°F (15°C).

Indoor Air Quality Issues
Mold issues and the accompanying mycotoxins can have a health effect on a diverse group of individuals. Mycotoxins are diverse secondary metabolites that are naturally produced by a wide variety of molds. The health effects are often counterintuitive, as many building occupants may be unaffected, while some individuals may have severe symptoms, including allergic reactions, infections (mycosis), or toxic effects.

Molds are fungi that are present both indoors and outdoors, growing in environments with humid or wet conditions. One mold species may produce several mycotoxins, and different molds may produce the same mycotoxin. Excess moisture is the underlying cause of mold growth, so preventing this condition is the most cost-effective solution. This is generally the best alternative to Filtration or Dilution Ventilation. In recent years, there have been many cases concerning mold in commercial buildings in multiple states, with many cases in Texas, Florida, and California.

The Effect of Moisture on Mechanical Insulation

Thermal Insulation, such as that used to insulate mechanical systems, depends upon being kept in a dry state to function efficiently. When a mass-type insulation becomes wet or has moisture infiltration, all or part of the air or gas spaces become filled with water. (In the case of a foamed cellular glass insulation, an inadequate or damaged vapor barrier allows water accumulation against the mechanical surface (such as piping or ductwork). This moisture will also migrate to the outer jacketing materials, creating mold growth opportunities. Heat transmission through water or water-filled spaces approaches the conduction rate of water instead of the conduction rate of air or gas. The conductivity of water at 70°F mean temperature is 4.1 Btu/sq ft./ hr. in °F, as compared to 0.17 for air. This means that heat transmission across space is approximately 24 times greater than when the space is filled with air.

Vapor Barriers

Mechanical Insulation applied to piping, ductwork, or equipment that operates at temperatures less than the ambient air temperature with a lower temperature surface causes a lower vapor pressure area than exists in the adjacent ambient air. Moisture in the vapor state in the ambient air seeks to equalize the pressure difference and attempts to flow to the lower temperature surface. If there is a barrier between the low- and high-pressure areas, the vapor will seek to reach the lower temperature area by infiltrating any gaps, punctures, joints, or voids, or through the barrier. Vapor will pass through most materials, some more quickly than others. Only a completely intact vapor barrier can prevent this transmission. As most vapor barriers become compromised through mechanical movement, maintenance activities, or other events, it is imperative that complete, effective vapor stops are installed during the mechanical insulation installation process.

Without proper vapor barriers and correctly installed vapor stops, the vapor passes into the mechanical insulation system, eventually reaching its dew point temperature. The vapor then condenses into a liquid. This water then replaces some of the air in the insulation system, filling the insulation with water and losing most of its thermal properties. The problem is exacerbated in areas with high relative humidity and is accelerated with significant temperature differences (Δt).

When cellular glass (such as foamglas®) is used, because it has a low vapor permeability rate, many fail to recognize or implement the additional installation processes needed to make cellular glass insulation system installation completely successful. Vapor barriers must be installed on the warm side of the system to prevent any moisture infiltration across the entire surface and all associated devices, such as flanges, valves, pumps, etc., and any device penetrants must be completely sealed. Cellular glass insulation systems should seal joints with resilient mastic, filling the cut cells and preventing moisture transmission. The chosen installed mastic must remain resilient at low temperatures, not harden or shrink, and create a complete envelope, preventing moisture migration inward toward the low-pressure area.

The inspection and maintenance of below-ambient mechanical insulation systems and their vapor barriers must include periodic inspections looking for pinholes, tears, ruptures, or any other breaches of these systems. When breaches are found in the vapor barrier/ insulation system, they should be immediately addressed to prevent additional system failures.

A study was conducted in a joint effort by the National Insulation Manufacturers Association, Union Carbide Corporation, and West Virginia University, evaluating Economic Thickness of Thermal Insulation on Cold Surfaces, completed in 1962. This study concluded that the cost of capital investment in refrigeration equipment/ systems, with the cost of power generation and other associated costs, meant that the mechanical insulation thickness necessary to prevent condensation was greater than the generally calculated economic thickness of the mechanical insulation, except for a few rare instances.

Mechanical Insulation Codes & Standards
Currently, for Mechanical Insulation, there are:

NO - National Standards
NO - Universal Energy Policies
NO - Best Design Practices

Some engineers recommend using the International Energy Conservation Code (IECC).
However, most localities have no regulatory requirements to ensure that contractors follow existing energy codes.

Temperature Difference Calculations
Mechanical Insulation is used to minimize the temperature change of a fluid from one location to another.

In fluid systems, the temperature drop can be calculated using the following equation:

$$(Ti - Tf) = (Ti - Ta) * [l - e^{-[(U*P*L)/(m*Cp)]}]$$

Ti = initial (entering) fluid temperature, °F
P = outside perimeter of pipe or duct, ft

Tf = final (leaving) fluid temperature, °F
L = length of pipe or duct run, ft

Ta = ambient temperature, °F
m = flow rate of fluid, lbm/hr

U = overall heat transfer coefficient, Btu/(hr*ft²*°F)
Cp = specific heat of fluid, Btu/(lbm·°F)

IRR: Internal Rate of Return: The Internal Rate of Return (IRR) is the discount rate that makes the The Net Present Value (NPV) of all cash flows (both costs and savings) from a particular project equals zero. IRR ignores external factors such as interest rates and inflation rates.
Both the high and low rates must be determined through trial and error using the NPV equation.

The formula for calculating IRR is shown below:

$$Internal\ Rate\ of\ Return\ (\%) = R1 + ((NPV1 * (R2 - R1)/(NPV1 - NPV2))$$

Formula for calculating IRR

- **R1 =** *Lower Discount or Return Rate*
- **R2 =** Higher Discount or Return Rate
- **NPV1 =** Higher Net Present Value
- **NPV2 =** Lower Net Present Value

Interpreting your IRR can help your team make better project investment decisions. It provides additional information to an NPV and demonstrates cash flow advantages, disadvantages, and the return on project investments. IRR works best for projects with low realizable capital gains because it is more difficult to calculate risks and payoffs accurately for longer periods when calculating Net Present Value (NPV).

We have conservatively postulated the useful life of mechanical insulation to be 20 years (the industry standard for most mechanical insulation is 30 years). Therefore, we have projected your energy savings to extend to 20 years for the purposes of this equation.

NPV - (Net Present Value): The Net Present Value or (NPV), of a project's range of cash flows (in this instance, cost and savings), adjusts future earnings to reflect their value in present day dollars. The formula we are using for NPV is:

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} = 0$$

- **N =** time period
- **n =** the current period, usually in years
- **r =** the internal rate of return
- **C =** yearly amount of interest received

The low rate will always be determined by estimating a **positive** NPV close to zero, while the high rate will always be determined by estimating a **negative** NPV close to zero.

We have conservatively postulated the useful life of mechanical insulation to be 20 years (the industry standard for most mechanical insulation is 30 years). Therefore, we have projected your energy savings to extend to 20 years for the purposes of this equation.

Simple Payback: is the time it will take to recover installation costs based on the annual energy cost savings.

This equation is for Simple Payback is:

$$Simple\ Payback = \left\{\frac{(Installation\ Cost\ including\ Labor\ and\ Materials)}{(Annual\ Energy\ Savings\ for\ this\ project)}\right\}$$

The Simple Payback we use, <u>DOES NOT</u> include calculations for the cost savings of longer equipment life cycles, reduced energy consumption for support equipment, (including electrical control systems, make-up hydronic systems, etc.) reduced chemical treatment/ filtering of boiler & chiller systems, increased production labor efficiencies (due to better working environments), etc.

Additional/ Other observed information

We did not observe any asbestos-containing material content, lead-based paint, or other hazardous materials in our study. Older MIS may contain asbestos materials, lead, hazards such as naturally occurring infectious disease-causing bacteria, mold, and other chemical hazards, which need to be identified, sampled, and confirmed through laboratory analysis. The reduction of these hazards is another potential advantage of performing the recommended upgrades, as well as the replacement of any damaged system materials.

Optimum insulation thickness was determined by evaluating existing mechanical insulation support systems, visual inspection of mechanical system installation, information provided by the client and/ or engineering staff concerning existing mechanical systems, and 3E Plus® Program optimization calculations if sufficient engineering data was provided to our mechanical insulation study team.
To perform the enclosed Mechanical Insulation System Study, we have used meticulous, complex research in conjunction with knowledgeable and competent mechanical insulation experts to provide practical and realistic results.

For this report, we used Energy Conservation Measures (ECM) based on “Simple Paybacks.” In comparison, a simple payback analysis has some shortcomings, such as ignoring the issue of an ECM providing continuous, ongoing energy savings returns. Our strategy for reporting information, data collection, and associated calculations provided in this report is to be conservative, ensuring your energy savings are based on minimum savings. This allows you to have confidence that you will realize, at a minimum, the dollar and BTU savings presented in this report. We believe that the simple payback calculation process is the best choice to give you the relevant information, in a timely manner, needed to assist you in your decision-making process.

Mechanical insulation industry standards expect a life cycle performance of thirty years. For many Energy Service Companies (ESCO), an ECM must have a payback of less than seven years to be attractive enough to be included in their evaluations. As this report documents, the savings for this project are expected to exceed those expectations when remediation costs are secured from qualified, competent contractors.

Our survey was conducted in a facility that would have been initially designed as practically as possible based on the energy standards at the time of the engineered design. As this report is based on current energy data, current cost of energy, current polluting emission data for energy generation, and mechanical insulation system performance, the recommendations included provide the best potential paybacks for the existing facility without an interruption of existing mechanical system function or major mechanical system retrofits.

To provide a more integrated mechanical insulation study would require significant additional expense, with an immense amount of extra data evaluation. The five major steps normally considered by energy engineers to be necessary for an integrated energy evaluation include a thorough energy inventory, an engineering overview, data collection, comprehensive analysis, and a final report. Completion of this process is normally a multiyear process. Since Mechanical Insulation installation has significant energy savings, as soon as the remediation process is instigated and mechanical insulation begins to be installed, the significant time and expense that is needed to perform an integrated mechanical insulation system would result in continued energy loss, with the associated lost savings opportunity, and potentially shortening of mechanical system equipment life cycles.
Although we recorded a Wind Speed of 1.4 mph in one of the Mechanical Rooms, we used a wind speed of less than 1 mph to remain conservative with savings calculations.

Heat Flow

Insulation product ratings, including mechanical insulation, are based on resistance to heat flow. Measured in R-value units in the United States and RSI in Canada (RSI = R × 0.1761). The inverse of thermal resistance is conductance, referred to as the U-value (U = 1/R or USI = 1/RSI). U is measured in Btu/ square foot-°Fahrenheit-hour units in the United States. In Canada, U is measured in watts/ square meter-Celsius. The higher the R-value, the better the insulation properties. If temperature scale conversions were needed, we used the following for our report:

Temperature Scale	Convert to/ by	
Fahrenheit/ to Celsius	°F = 1.8°C + 32°	
Celsius/ to Fahrenheit	°C = 5/9(°F-32°)	
Rankine	°R = 1.8K + 0.6°	°R = °F + 459.67
Kelvin	K=5/9(°R-0.6°)	K = °C + 273°

U-value is more useful for calculations since it describes the actual amount of energy (heat flow) that can move through the material for each degree Fahrenheit (°F) difference in temperature (Δt) from one side of the material to the other. R-values of different components can be added (Such as for different product layers of differing products, for example, insulations with jackets or with different wall components), but U-values cannot be directly added. Most forms of mechanical insulation use pockets or chambers of air or gas to decrease the material's conductivity because a gas conducts heat energy more slowly than a solid.

Some consider Mechanical Insulation a commodity with the lowest cost as the prime driver in contractor selection. The quality of work of an insulation contractor can drastically affect your facility's efficiency and overall condition. It is imperative that mechanical insulation be properly installed, routinely inspected, maintained correctly, and, if needed, replaced. Not choosing a qualified contractor specializing in Mechanical Insulation installation has led to a multitude of issues for facility owners and stakeholders, including mechanical system failure, excessive fuel costs, forced plant outages, hazardous material releases, facility personnel liability, safety relief valve set point drift, uncomfortable & noisy working environments, etc. Selecting the best mechanical insulation contractor is essential for your project timelines, budgets, and future energy expenditures.

Organizations that Review, Test, and/ or Certify Compliance with Industry Standards:

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers.
ASHRAE was formed as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers by the merger in 1959 of the American Society of Heating and Air-Conditioning Engineers (ASHAE), founded in 1894, and the American Society of Refrigerating Engineers (ASRE), founded in 1904. Certification programs were developed to meet Energy Evaluation industry needs and to provide value to built-environment professionals, employers, & building owners. Certifications like Building Commissioning Professional (BCxP) and Building Energy Assessment Professional (BEAP) are recognized by the U.S. Department of Energy (DOE) as meeting the Better Buildings Workforce Guidelines (BBWG) and are used frequently by local jurisdictions to designate who is qualified to perform benchmarking and energy assessments.

ANSI - American National Standard Institute.
ANSI/ASHRAE/IES Standard 100-2018 sets criteria to reduce energy consumption through improved energy efficiency and performance in existing buildings. It applies to existing buildings, portions of buildings, and building complexes, including the envelope & all systems. The standard, however,

excludes industrial and agricultural processes in buildings for which the energy targets do not include these processes. This Standard details guidelines for operation & maintenance and energy use as an energy management plan, including the methods of implementation & verification. It details information relevant to residential & nonresidential buildings.

AEE - Association of Energy Engineers. AEE is a non-profit professional society founded in 1977. The mission of AEE is “to promote the scientific and educational interests of those engaged in the energy industry and to foster action for sustainable development. AEE is a network of over 18,000 members and 25,000 certified individuals in over 100 countries.

ASHRAE Standard 211 – The AEE certification programs for CEM & CEA meet the criteria of an energy auditor and are qualified to perform work under ASHRAE Standard 211-2018 for Commercial Building Energy Audits. The CEM certification from the Association of Energy Engineers is accredited by the ANSI National Accreditation Board (ANAB) based on the International ANAB/ISO/IEC 17024. ANAB Standard 17024 is considered by many in the industry to be the highest standard in personnel certification accreditation.
EIA - The U.S. Energy Information Administration. EIA is a principal agency of the U.S. Federal Statistical System. The U.S. Energy Information Administration collects, analyzes, and disseminates independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding of energy and its interaction with the economy and the environment.

BPI—Building Performance Institute, Incorporated. BPI certification programs were developed to meet Building Energy Evaluation Industry Standards for Residences. Energy Evaluation industry standards use evaluations using diagnostic equipment and modeling software to identify areas for energy savings, provide a prioritized scope of work, and produce an audit report.

NREL - **National Renewable Energy Laboratory.** NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency & Renewable Energy Operated by the Alliance for Sustainable Energy, LLC. NREL advances the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies and provides the knowledge to integrate and optimize energy systems.

NIA – National Insulation Association. NIA is a not-for-profit trade association representing the contractors, distributors, laminators, fabricators, and manufacturers that provide thermal insulation, insulation accessories, and components to the nationwide commercial, industrial, and institutional markets.

NMIC – National Mechanical Insulation Committee. The overall objective of NMIC is to identify, develop and disseminate information related to mechanical insulation in commercial and industrial applications by examining current policies, procedures and practices; identifying research or testing needs; developing recommendations utilizing the best science and information available; providing education and awareness programs as to the merits and value of proper insulation systems and to establish a roadmap to implement improvements in design, insulation system selection and establish application best practices.

Certifications and Standards for Mechanical Insulation used on Piping.
Temperature Ranges from 40°F to 1400°F (4°C to 700°C), per ASTM C547

Codes, Standards, and consideration of future energy costs, generation sources, and potential pollution emissions due to energy generation sources play an important role in the information that is used to design, manufacture, and install mechanical insulation on piping systems.
When evaluating a mechanical insulation system, engineering design standards have been tested and evaluated for energy flow reductions, life cycle performance, installation costs, life safety parameters, return on investment, stakeholder safety, and potential health hazards.

Numerous codes and standards exist in the United States and Canada that are specifically designed to ensure the safe, quality installation of commercial and industrial mechanical insulation piping products.

The enclosed codes and standards provide a means for achieving consistent, predictable technical performance when installed according to the manufacturer's recommended installation techniques. These techniques are then used to create standard guidelines.

The availability of imported non-compliant products that do not meet the same standards regarding quality, life-safety, energy reduction, installation, and life cycle performance has been growing. To avoid potential future liability, it is imperative that specifiers are familiar with recommended mechanical insulation products that have been tested and proven to meet the claims made in the manufacturers' data/ submittal sheets.

The potential for extremely costly consequences for using mechanical pipe insulation that does not meet established quality, technical and safety requirements include some of the following: Energy Loss, Thermal Conductivity – Unstable thermal conductivity of a mechanical insulation over time, that increases due to mechanical and/or chemical instability could lead to greater energy loss than predicted in the original design. (ASTM C177, ASTM C335 and ASTM C447)
Safety & Health Risks due to Chemical and/ or Physical Deterioration – A mechanical insulation material not conforming to standards and codes could thermally and chemically deteriorate from "runaway" exothermic processes when first installed on hot systems. This can pose a threat to safety and health. In addition, "runaway" exothermic processes can damage the insulation materials, leading to excessive energy loss not predicted in the engineering design (ASTM C411 & ASTM C447) – This problem can present Safety risks to facility employees, the public and mechanical insulation installers, with potential liability concerns.

Increased operational and maintenance costs for the facility owner.

Reduced process control engineering design parameters
Greater installation costs for all stakeholders – The installation costs will escalate when mechanical piping insulation does not correctly fit the corresponding piping. (ASTM C302 and ASTM C585)

Mechanical Insulation Gaps Affecting Performance and Energy Loss—If the product does not fit correctly, it will more likely not be "correctly closed," leading to continuous energy loss or gain for the system and impacting system performance (ASTM C356).

Exceeding maximum or minimum temperature engineering system designs
Combustible Gases – when mechanical insulation is exposed to a fire, and the result is a large release of combustible gases, the gases could further feed the fire (ASTM E13)
Dimensional stability (lineal shrinkage with heat soak and sag resistance)
Facility/ system failure, including the potential for safety valve failure due to set point drift
Extreme system temperature fluctuations

If installers, designers, manufacturers, specifiers, fabricators, engineers, and contractors do not adhere to the standards and codes for mechanical insulation piping systems, specific problems can arise, including liabilities for various stakeholders, including owners and/or contractors.

Some of the Codes and Standards we reviewed with this project include the ASTM Standard Specifications for Insulation and Facing Materials. The ASTM Reference Numbers for various mechanical insulation products include the following:
Calcium Silicate ASTM C533 – Standard Specification for Calcium Silicate Block and Piping Thermal Insulation
Elastomeric – ASTM C534 Standard Specification for Preformed Flexible Elastomeric Cellular Thermal Insulation in Sheet and Tubular Form
Mineral Fiber ASTM C547 – Standard Specification for Mineral Fiber Pipe Insulation
Cellular Glass ASTM C552 – Standard Specification for Cellular Glass
Polystyrene – ASTM C578 Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation
Metal Mesh Covered Mineral Fiber Blankets ASTM C592 – Standard Specification for Mineral Fiber Blanket Insulation and Blanket Type Pipe Insulation (Metal Mesh Covered) (Industrial Type)
Perlite ASTM C610 – Standard Specification for Molded Expanded Perlite Block and Pipe Thermal Insulation
Mineral Fiber – ASTM C612 Standard Specification for Mineral Fiber Block and Board Thermal Insulation
Vapor Retarders – ASTM C755 Standard Practice for Selection of Water Vapor Retarders for Thermal Insulation
Jacketing Materials for Thermal Insulation ASTM C921 – Standard Practice for Determining the Properties of Jacketing Material for Thermal Insulation.
Fibrous Glass Blanket – ASTM C1290 Standard Specification for Flexible Glass Blanket Insulation used to Externally Insulate HVAC Ducts
Mineral Fiber Pipe and Tank Wrap ASTM C1393 – Standard Specification for Perpendicularly Oriented Mineral Fiber Roll and Sheet Thermal Insulation for Pipes and Tanks

CALCULATING R-VALUES OF INSULATION
What Is R-Value?
The “R” value designates an object's thermal Resistance. The higher the R-Value, the higher the thermal resistance and, therefore, the higher the insulating value.

How is the efficiency of Thermal Insulation calculated (R-value)?
Thermal Insulation efficiency is calculated by multiplying the thickness of the insulation in inches by its thermal conductivity.

For example, a 2" thick sheet of insulation with a thermal conductivity 1 of 0.25 Btu•in/h•ft2•°F has an R-Value equal to 2 divided by 0.25 or 8.0

FLAT OBJECTS
R-values for flat objects, such as sheet insulation, are easy to calculate.
It is the thickness of the insulation in inches divided by the thermal conductivity of the insulation.
For example, a 2" thick sheet of insulation with a thermal conductivity 1 of 0.25 Btu•in/h•ft2•°F has an R-Value equal to 2 divided by 0.25 or 8.0.
R = Thickness / k
Example: 2 / 0.25 = 8.0

This simple equation is true for any flat, homogeneous material with parallel surfaces, and it means the R-value increases proportionally to the thickness.

CYLINDRICAL OBJECTS
The simple equation for R-value does not hold for cylindrical objects like pipe insulation.

For these objects, the heat flow is not the simple straight-through heat flow used for flat objects. Instead, heat flow is radial because the inner surface area is much smaller than the outer surface area, and the R-value calculation must consider this.
The equation for the R-value of cylindrical objects is as follows:
Where r1 = uninsulated pipe radius in inches
r2 = insulated pipe radius in inches
k = thermal conductivity
In = Natural Logarithm2
R = r2 In (r2/r1) / k

Based on this equation, the R-value increases as the insulation thickness increases and the pipe sizes decrease.
For example, 1" thick insulation will have a higher R-Value on a 1" pipe than on a 3" pipe.

Consequently, the R-value of insulation on a pipe must always be determined by considering the pipe size and insulation thickness.

1. Most insulation materials' thermal conductivity (k) is found on the technical data sheets, which are available from the insulation material manufacturer.
2. The Natural Logarithm (ln) is found on most scientific calculators and in Excel spreadsheet calculations.

Estimating Heat Loss / Heat Gain
To calculate energy loss/ savings, the following information must be considered.

Fourier's law governs Steady-state, one-dimensional heat flow through insulation systems:

$$q = - k \cdot A \cdot dT/dx \quad (1)$$

where:

q = rate of heat flow, Btu/hr
A = cross-sectional area normal to heat flow, ft^2
k = thermal conductivity of the insulation material, Btu-in/h ft^2°F
dT/dx = temperature gradient, °F/in

For flat geometry of finite thickness, the equation reduces to:

$$q = k \cdot A \cdot (T_1–T_2)/X \quad (2)$$

where:

X = thickness of the insulation, inches (in.).

For cylindrical geometry, the equation becomes:

$$q = k \cdot A_2 \cdot (T_1–T_2)/(r_2 \cdot \ln (r_2/r_1)) \quad (3)$$

where:

r_2 = outer radius, in.
r_1 = inner radius, in.
A_2= area of outer surface, ft^2

The term $r_2 \ln (r_2/r_1)$ is sometimes called the "equivalent thickness" of the insulation layer. Equivalent thickness is the thickness of insulation, which, if installed on a flat surface, would yield a heat flux equal to that at the outer surface of the cylindrical geometry.

Heat transfer from surfaces is a combination of convection and radiation. Usually, it is assumed that these modes are additive, and therefore, a combined surface coefficient can be used to estimate the heat flow to/ from a surface.

3E Plus® Calculation of Energy Flows:

3E Plus® uses the **heat flow calculation method** described in **ASTM C680** titled Standard Practices for Determination of Heat Gain or Loss and the Surface Temperature of Insulated Piping on Equipment Systems by Using a Computer System.

The ASTM C680 Assumptions include;

Steady State Heat Transfer (i.e. invariant with time)
One-dimensional heat transfer
3E Plus Software assumes all surface temperatures have the same value for all energized surfaces throughout the year.

This software is a valuable energy efficiency tool for calculating the energy used in a mechanical system. The program provides statistical information to be used in conjunction with site-specific information to assist in making determinations to help prioritize insulation system upgrade budgets and schedules and project scopes of work based on payback timelines.

Mechanical insulation costs are highly variable and dependent on the location of the job, local labor rates for qualified installers, market conditions, productivity, project size, and complexity. The 3E Plus® program contains an algorithm to estimate installed costs for multiple insulation materials. These algorithms were originally developed under a contract from the Federal Energy Administration (FEA), Office of Industrial Programs. These algorithms were intended as a guide. We have used specific local pricing for our calculations to ensure accurate payback data inputs, if available/ appropriate.

Fuel Comparisons
The table below shows heating values in BTUs for various types of fuels, which we used for any necessary calculation conversions.

Type of Fuel	**Unit**	**BTUs**	**MMBTU's**
Natural Gas	1 MCF	1,000,000	1.0
Natural Gas	1 Therm	100,000	.10
Electricity	1 kWh	3,413	.003413
Fuel Oil #2	1 Gallon	139,000	.139
Fuel Oil #6	1 Gallon	150,000	.150
Propane	1 Gallon	91,600	.0916
Gasoline	1 Gallon	125,000	.125
Coal	1 Pound	12,250	.012250
100 PSIG Steam	1 Pound	1,100	.0011
Wood	1 Pound	9,000	.0090

Useful heat delivered by heating systems is calculated by multiplying the heating efficiency of the equipment by the heating or thermal value of the fuel. When one therm of gas is used in a boiler that is 75% efficient, then the actual useful heating is calculated as:

100,000 BTU's x 75/100 = 75,000 BTU's

The cost of heating with different fuels can be compared on an MMBTU (million BTU) basis.

The equation below finds the cost per MMBTU for any fuel and delivery equipment/ system.

$$\$/\text{MMBTU} = \left\{ \frac{(\$/\text{Fuel Unit})}{(\text{MMBTU}/\text{Fuel Unit x Efficiency})} \right\}$$

Physical Inspection / Walk-Through Recommendations
Monitoring mechanical insulation can be daunting if it becomes neglected or ignored for a period of time. Routine inspections are recommended. The inspection frequency will vary depending on many issues: weather exposure, physical abuse, renovations, maintenance or upgrades to the mechanical systems, etc. It is recommended that an inspection be performed every 6 months. The frequency of such inspection can be further evaluated, either increasing or decreasing the frequency based on the condition of the insulation.

The experience and qualifications of the inspector is important to the comprehensiveness of the mechanical insulation system assessment. In-house and third-party inspections can be performed. In-house inspections may initially be more expensive and require qualitative inspection team training. We can provide that basic training either by assisting with actual inspections and/or training with more formality.

Third-party inspections may offer more complete and thorough results. Either way, we would assist you in making the proper decision.

This inspection requires physically walking around the building or plant, which is usually more challenging than it might sound. Preparation for this step will greatly improve the time and efficiency of the physical inspection. The LMCT has developed a worksheet for you to follow.

The first step is to ensure all safety precautions are adhered to within the inspected facility. The inspection begins at the source. Ensure that the inspector has the required safety requirements and PPE. Some of the necessary PPE includes, but is not limited to:

- Site-specific safety requirements of the building or facility, including any safety manuals.
- Following all Federal, State, & Local safety regulations and site-specific safety policies.
- Safety shoes
- Appropriate clothing—crawling on the ground and climbing ladders may be involved. Long-sleeved shirts are recommended to reduce arm contact burns.
- Safety Glasses
- Hard hat
- Earplugs
- Gloves
- High visibility clothing
- Safety Harness & fall protection equipment

The inspection team is ready to start the walk-through once all the safety concerns and logistic issues are met. Using the provided Insulators LMCT Mechanical Insulation Worksheet as a guide will help to ensure you obtain the information needed for a quality inspection. If using photography or infrared imaging to document any deficiencies, permission should be obtained prior to the assessment. Infrared imaging and digital photography are often a large part of the evaluation. A quality evaluation can still be performed without infrared imaging; however, these devices help expose moisture issues, thermal anomalies, mold, and other potential issues, exposing opportunities for improvement. Infrared images and digital pictures help document existing conditions and offer tremendous credibility to the evaluation. The following are the recommended items that you should have with you while conducting the mechanical insulation system investigation:

- Notebook or small case to hold paperwork and/ or backpack to carry tools, instrumentation, cameras, etc.
- If available, a copy of the specifications that you could research as it is inspected. It is not a necessity, but it may be referenced when applicable.
- Several copies of the Insulators LMCT Mechanical Insulation Worksheet (MIW)
- Clipboard and pencil/pens
- Flashlight
- Calculator
- Anemometer
- Tape measure and measuring wheel
- Non–contact thermometer
- Standard Digital Camera
- Thermal Imaging Camera
- Ladder

Evaluation Basics

Be focused on the purpose of the evaluation. It will be easy to get distracted. Stay focused on a system, large or small. Several worksheets may be needed to gather the required information. The more experienced the evaluator becomes, the easier this will become. Document as much as possible because this data will be used to input data and develop the final report. Not having to go back after completing the walk-through is valuable and saves time.

Use the supplied **Mechanical Insulation Worksheet**. This worksheet will ask many questions to fill in. Be prepared to take additional notes and comments. Do not tackle too much at first. There should be several worksheets for each unit. Familiarity with the worksheet will increase your efficiency.

Identify the specification area in which the information is being obtained. Plan on using several worksheets for a system. Mark, make sure the location is identified. And develop a number system by dedicating a worksheet number.

Check off only one to identify the piece of equipment. The evaluation should only incorporate one type of equipment. There is space in the middle to write something that was not listed or to add additional notes.

Mechanical Insulation Worksheet
System Data Collection

Directions: Use this collection worksheet to gather the information needed for the evaluation. Use separate worksheets to break down the system that is being evaluated. In many cases multiple sheets will be needed even for one system. Do not include more than one system on a sheet.

Person collecting data: ______________________ Date: ___________ Worksheet #: _______

Building # _______ Floor ______ Location ______________________ System ID ___________

***Equipment type** & **Size**. Only check one. Use another worksheet for additional components.*

- ☐ Boiler
- ☐ Furnace
- ☐ Chiller
- ☐ Condenser
- ☐ Coil Unit
- ☐ Heat Exchanger
- ☐ Vessel (Process)
- ☐ Tank
- ☐ Unit Local Heater
- ☐ Hot Duct/ Breeching (above ambient)
- ☐ Cold Duct (below ambient)
- ☐ Dual Duct (above & below ambient)
- ☐ Hot Piping (above ambient)
- ☐ Cold Piping (below ambient)
- ☐ Dual Piping (above & below ambient)
- ☐ Refrigerant lines
- ☐ Valves
- ☐ Other Devices/ Connectors

Equipment Material

- ☐ Steel
- ☐ Stainless Steel
- ☐ Copper
- ☐ PVC
- ☐ Other

Pipe or Tube

- ☐ Horizontal
- ☐ Vertical

Pipe Size ______

Pipe Length______

Duct

- ☐ Horizontal
- ☐ Vertical

Width __________

Length __________

Length __________

Total Sq Footage

Tank or Vessel

- ☐ Horizontal
- ☐ Vertical

Width __________

Length of Cylinder

____

Head of Tank (D^2)

Average Operating/ process temperature ________(If a dual temperature system, use separate sheets using one for hot & one for cold)

Operating Hours per year (8760 max) ________

Ambient Environment:

☐ Inside (Controlled Environment)

Average Temperature _______

☐ Outdoor (Exposed to Weather)

Average Temperature _______

Average Windspeed _______

Mechanical Insulation Information

Thickness_______ Material Type _______________

Metal/ PVC/ ASJ Jacketing ☐ Yes ☐ No

Equipment or Pipe 100% Insulated ☐ Yes ☐ No

If No, % insulated __________(approximate)

or

Missing or Damaged Insulation footage ________(a)

Total Pipe/ Duct/ Equipment Footage__________(b)

Divide (a) by (b) to equal % missing ____________

Lengths of pipe runs or ducts could be estimated, but try to be as accurate as possible.

Every unit has a designed operating temperature, which the facility engineering departments should be able to supply. If that is not available, take several temperature readings of a bare surface. If calculations are going to be performed to determine the cost of lost energy, lost BTUs, and environmental gas emissions, then additional information is needed, including the ambient and system design temperatures in the ambient air where the equipment or system is located. If the system is outside, the seasonal averages of temperatures and wind speeds are needed. One resource for this information is www.weatherbase.com.

The mechanical insulation information section is essential in analyzing the operating performance efficiency of mechanical insulation systems. You must scrutinize the entire system, including any deficiencies or visual issues. Damaged, crushed, wet insulation, compromised jacketing, or vapor barriers should be documented. The estimated percentage of damaged, missing, or compromised insulation and associated jacketing materials may be a significant factor in the system evaluation.

Look for deficiencies, including but not limited to:

- Missing insulation
- Wet insulation
- Crushed insulation
- Thermal Anomalies
- Mold – black spots
- Protective jacketing
- Weather and/ or Vapor barriers
- Uninsulated mechanical devices
- Valve Bonnets, Unions, Flanges, etc.
- Any Visual Mechanical Anomalies
- Gaps in insulation joints
- Improperly supported Piping or duct
- Non-functioning valves, pumps, or equipment

Page 2 is self-explanatory, and this information will be helpful in the evaluation. A few questions pertain to the installation of the insulation. Unless documentation is available, the most pertinent information is the information documented
and obtained during the investigation. The evaluation is a “snapshot” of the system's actual performance during the investigation. If a system is not operational during the review, then we cannot make assumptions that may not be accurate during functional system operations.

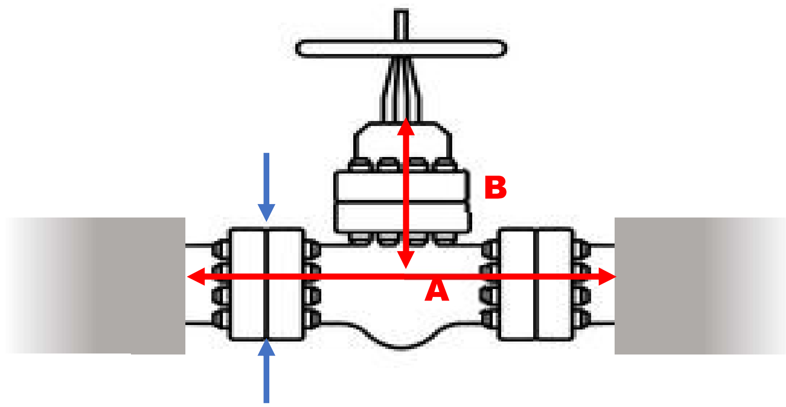
If you don't have a Thermal Imaging camera, many functions can be performed with a standard camera and a non-contact thermometer. An evaluation can still reveal mechanical insulation performance with potential areas for system improvement or upgrades. Infrared images do help to uncover and document thermal and moisture anomalies.

Reporting organizations with appropriate images for verification and documentation is essential to project management. Digital cameras automatically give a number (jpeg number) to the picture. As images are taken, write them down on the sheet, corresponding to the irregularities or deficiencies observed. Include additional comments and notes concerning issues that may influence system performance. Take photos of intact, well-performing insulation systems to compare when investigating “suspect underperforming systems. The investigation aims to gather as much relevant information as possible, which will help with current issues and assist with future planning, budgeting, and performance upgrades. The team can later determine the best course, maintenance, and system performance improvements.

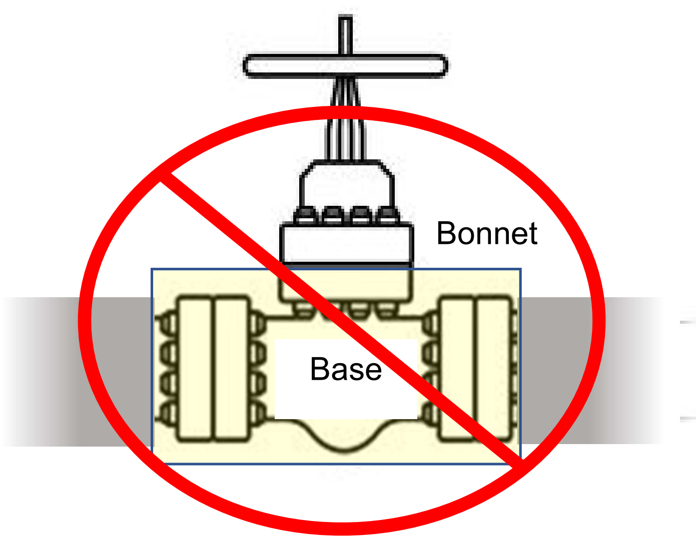
The ratings are used to expedite the evaluation timelines and help prioritize project schedules and budgets. The condition of the insulation will help explain the performance of associated mechanical systems.

- **Pipe** - steel, stainless steel, PVC, or copper tubing

- **Valves** - This incorporates many different types, but valves are the most common pipe/ tube control device. They are also subject to service and abuse. Lateral Ys and 45˚s strainers should be included as well. Many of these applications may use removable and reusable blankets. If they are not properly installed, it should be considered missing, as creating thermal breaks can lead to issues such as valve set point drift, warping of instrumentation, etc.



The final report should note having reusable blankets on the ground/ floor or missing their installation.



When installing Insulation, the Entire Bonnet should be insulated. Not just the valve's body, as in the image to the left.

Some of the most prevalent issues of insulated valves.

The insulation thickness may be greater than usual in cold applications. Many valve handles will not operate correctly unless the insulation is in place, and sometimes, the vapor barrier is compromised. The scrutiny of installation procedures is of critical importance to ensure issues related to condensation, rust, corrosion, mold, and wet insulation are not overlooked. “Valve Extensions” extend the value handle to permit proper entire valve operation without compromising the insulation's integrity.

The Body or Base of the valve is insulated, and the Bonnet is not. Many do not recognize the importance of insulating the entire valve, including the bonnet, to reduce thermomechanical stress and potential deformation or material failure. The bonnet/ stem is part of the valve and should be properly insulated.

If one valve is improperly insulated, there may be dozens, if not hundreds. Suppose they are in a similar condition. This deficiency alone can cause multiple mechanical system issues and is usually a significant energy loss and a potential risk to personnel protection.

- Elbows, 90ºs, and 45ºs – These are some of the most common types of fittings. Connecting piping or devices either by welding, soldered, screwed, or bolted with flanges or clamps. An evaluator should examine these devices for proper mechanical insulation installation. An infrared image often reveals improper thermal insulation under PVC or metal covers.

- Flanges, unions, and other piping connectors. It is essential to measure the flange's outside diameter. Consider the flange size and the linear measurement between the insulation and the distance to the outer diameter of the installed insulation to determine if the proper insulation has been installed. An infrared image will indicate significant voids or improper installation techniques.

Mechanical Insulation Worksheet
Physical Walkthrough / Inspection

Inspector: ______________________ Date: ____________ Worksheet #: ______

Document Resources Used
Check all that apply

- ☐ None
- ☐ Technical Specification
- ☐ Manufacture Specification
- ☐ Codes/ Regulatory Specification

5 Rating is Excellent
4 Rating is Good
3 Rating is Satisfactory
2 Rating is Poor but Acceptable
1 Rating is Unacceptable
N/A – Does Not Apply
SP – Standard Photography
TP – Thermographic Photography
- Photograph Number(s)

1. Insulation meets installation requirements	5	4	3	2	1	N/A	SP	TP	#_____
2. Insulation has been maintained	5	4	3	2	1	N/A	SP	TP	#_____
3. Insulation replaced after mechanical repairs completed	5	4	3	2	1	N/A	SP	TP	#_____
4. Water / Moisture damage of Insulation (no damage is 5)	5	4	3	2	1	N/A	SP	TP	#_____
5. Visible signs of mold growth (no damage is 5)	5	4	3	2	1	N/A	SP	TP	#_____
6. Physical abuse/ damage of insulation (no damage is 5)	5	4	3	2	1	N/A	SP	TP	#_____
7. General workmanship/ quality of installation	5	4	3	2	1	N/A	SP	TP	#_____
8. Integrity of finish: Metal, PVC, Paper, ASJ (paper)	5	4	3	2	1	N/A	SP	TP	#_____
9. Integrity of watershed & caulking	5	4	3	2	1	N/A	SP	TP	#_____
10. Insulation of Valves complete; Body & Bonnet	5	4	3	2	1	N/A	SP	TP	#_____
11. Condition of vapor barriers or vapor retarders	5	4	3	2	1	N/A	SP	TP	#_____
12. Valve extensions used to maximize insulation function	5	4	3	2	1	N/A	SP	TP	#_____
13. Damaged insulation due to chemical exposure	5	4	3	2	1	N/A	SP	TP	#_____
14. Damaged insulation due to condensation/ rust/ mold	5	4	3	2	1	N/A	SP	TP	#_____
15. Use of removable (pads/ blankets) properly replaced	5	4	3	2	1	N/A	SP	TP	#_____
16. Potential Asbestos or other harmful fiber release	5	4	3	2	1	N/A	SP	TP	#_____
17. Obstructions do not permit proper insulation thickness	5	4	3	2	1	N/A	SP	TP	#_____
Overall appearance of insulation	5	4	3	2	1	N/A	SP	TP	#_____

Additional comments, notes, observation or comments concerning the mechanical insulation?

Pipe, Tube &Fittings Data Collection

Bare Pipe Data

*Pipe Size ________
Straight Linear Measurement of **Bare Pipe
____
Temperature readings. More the better, then average.
_______ _______ _______ ______ ______
_______ _______ _______ ______ ______
_______ _______ _______ ______ ______
Reading taken at ______ intervals

AVERAGE Temperature of Bare Pipe_________

*Different pipe sizes require separate analisys.
** Crushed, wet or <10% damaged insulation, consider it bare.
☐ Standard

Insulated Pipe Data

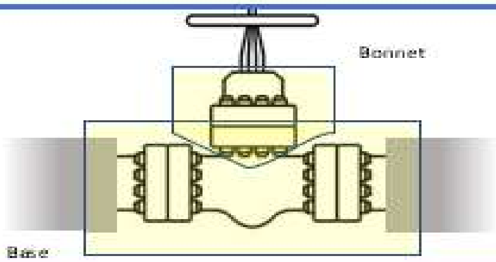
*Insulation Thickness ________
Straight Linear Meas. of **Insulated Pipe
____
Temperature readings. More the better, then average.
_______ _______ _______ ______ ______
_______ _______ _______ ______ ______
_______ _______ _______ ______ ______
Readings taken at ______ intervals

AVERAGE Temperature of Insulated Pipe_________

*Different Thickness' require separate analisys.
** do not include crushed, wet or <10% damaged insulation.

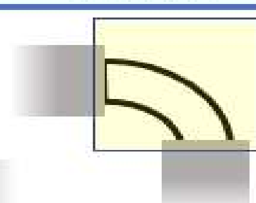
Valve Data

of Bare Valves _______ Size of Bare Valve
____
Size of Bare Flange ________ if applicable
Temperature of Bare Valve_________
Base (B) + Bonnet (A) = Total distance _________
# of Valves only Base insulated _______
Cold Application:
Vapor Barrier is sealed ☐ Yes ☐ No
☐ Standard
☐ Thermal Image Photo(s) # _______



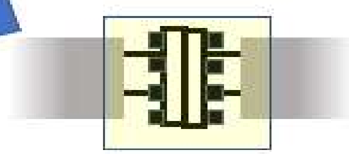
90° or Elbow Data (include 45°)

of Bare 90°s _______
☐ Socket type ☐ Short Radius ☐ Long Radius
If a Sweep type, treat it as linear piping.
Size of Bare 90°s ________
Size of Bare 90°s Flange ________ if applicable
Temperature of Bare Pipe_________☐ Standard
☐ Thermal Image Photo(s) #

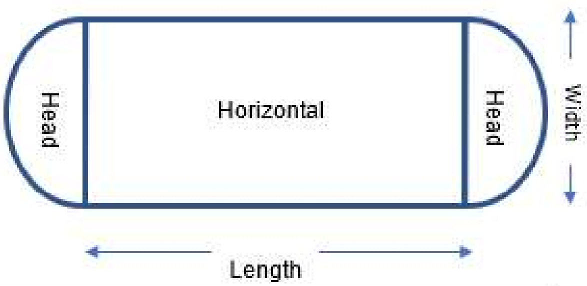


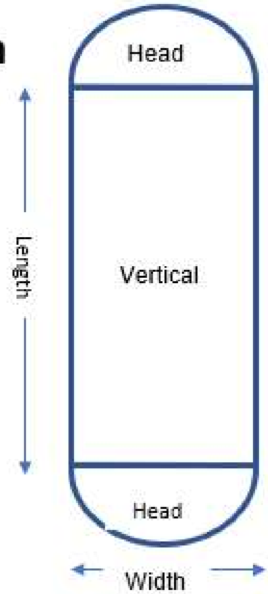
Flange or other Connections

of Bare Connections _______
Size of Bare Connected Pipe _________
Temperature of Bare Connection _________
Total length of opening _________
Vapor Barrier is sealed ☐ Yes ☐ No
☐ Standard
☐ Thermal Image Photo(s) #
____
Photograghy used, attach to document



Tank and Vessel Data Collection





Area Surface Calculations

(a) Body of Tank/Vessel = Length X Width
(b) Flat Head = πR^2 **or** Dome Head = $Width^2$
Body Area + Head Area (2 heads) = Sq footage of Tank /Vessel

a + b = Sq footage of Tank /Vessel

Bare Tank / Vessel Data

Total Surface Area of Unit _______
If particailly bare; ______ % not insulated
Temperature readings. More the better, then average.

_______ _______ _______ ______ ______

_______ _______ _______ ______ ______

_______ _______ _______ ______ ______

Reading taken at ______ intervals

AVERAGE Temperature of Bare Unit________

☐ Standard
☐ Thermal Image Photo(s) # _______

Insulated Tank / Vessel Data

Insulation Thickness _______
If particailly insulated; ______ % insulated
Temperature readings. More the better, then average.

_______ _______ _______ ______ ______

_______ _______ _______ ______ ______

_______ _______ _______ ______ ______

Readings taken at ______ intervals

AVERAGE Temperature of Insulated Tank _______

☐ Standard
☐ Thermal Image Photo(s) # ______
Photograghy used, attach to document

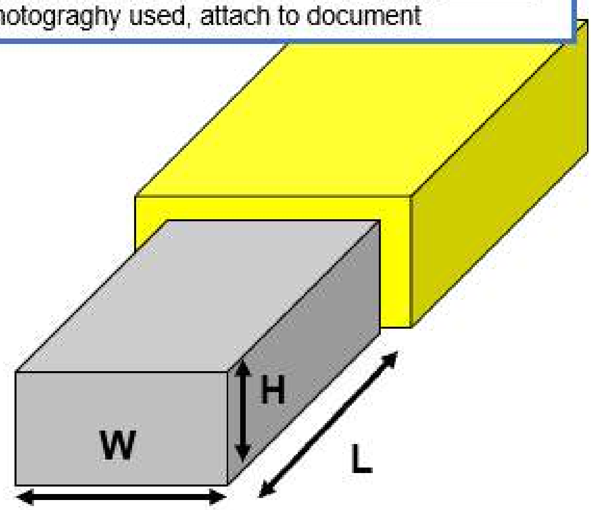
HVAC Ductwork Data

Total Surface Area = Width (W) x Height (H) x Length (L)
Total Surface Area of Unit _______
If particailly bare; ______ % not insulated
Temperature readings. More the better, then average.

_______ _______ _______ ______ ______

_______ _______ _______ ______ ______

AVERAGE Temperature of Bare Duct________
☐ Standard
☐ Thermal Image Photo(s) # _______
Photograghy used, attach to document



Tanks and/or Vessels are cylinders with heads, usually on both ends. A little math is used to calculate surface areas. This is often a source of tremendous energy losses. Ensure multiple readings are taken in different sections of the vessel. Suppose the insulation was not installed or supported correctly. In that case, vibration often leads to movement of the insulation, creating compression or gaps under the jacketing, not typically noticed from a visual observation. An infrared image will help to identify thermal breaks in the system. To calculate the energy lost from a vessel end, a flat head's area equation is πR^2. The calculated area for a dome requires a high level of math, such as calculus to get highly accurate calculations.
The previous Tank and vessel data collection worksheet will help you gather the information needed for Tank or vessel insulation energy calculations.

Ducts — Any square or rectangular surface, such as a breaching or a boiler conveying gases. If ducts are being used for dual system applications, hot and cold, then just like piping, they have to be insulated with proper vapor barriers to prevent moisture infiltration and premature corrosion of the mechanical system.

DENIS FORMULA

James S. Denis, President of MHG International Inc., based in Calgary, Alberta, first introduced the proposed "Standard Method of Measurement" in May 1980 to a World Insulation and Acoustic Congress (W.I.A.C.O.) held in Paris, France.

Later, in 1980, the 'Denis Formula' was introduced to major clients in the petrochemical industry. It quickly gained approval and acceptance as 'fair' to both client and contractor. It is now widely used in industrial projects. Quite apart from the obvious benefit of having one standard method of measurement for the industry, the formula brings economic benefits to the owner with ever-increasing acceptance and usage.

By identifying and defining the labor-intensive portions of the work, with factors to compensate for them, the formula balances by reducing 'unit prices.' The prices are now more appropriately based on the straight work, whereas previously, they had built-in difficulty factors at the time of tendering.

The use of the standard method of measurement (Denis Formula) has eliminated most of the guesswork.

The result benefits both the owner/client and the insulation contractor. By using the formula, the parties simplify the process of determining the final quantities and value of the work with strict control over the method.

STANDARD METHOD OF MEASUREMENT FOR INSTALLED INDUSTRIAL

These standards measure the quantities of insulation required for a mechanical system. They can also tend to, evaluate bids, and finalize accounts.

SCOPE

Insulation of mechanical systems includes but is not limited to, vessels, equipment, exchangers, pumps, tanks, ducts or flues, and pipework.

All measurements shall be taken on the external surface of the insulation system.

There shall be no deductions for surfaces not insulated within the specified insulation area. Exceptions to this rule may be negotiated where termination of insulation does not require a finish or weatherproofing and/ or where the uninsulated portion is more than 5% of the total.

Irregular shapes, fittings on piping systems, valves, etc., shall be counted separately. The formula's conversion tables are designed to include general requirements. Conversion factors for unusual items, e.g., seismological anchors or hangers, shall be negotiated by the parties prior to commencing the work.

All obstructions and penetrations of the insulation system shall be measured separately.

The complete applicable unit process will multiply All affected areas and pipe lengths.

DEFINITIONS

Types of insulation: hot, anti-condensation, cryogenic, acoustic, fireproofing.

General description of items to be insulated:

(a) Vessels

Towers, columns, drums, containers, receivers, exchangers, storage tanks, etc.

(b) Equipment

Equipment with an irregular outer surface, e.g., transitions, stiffeners, heads, roof ends, turbines, pumps, compressors, air or gas handling fans, etc.

Flat Surfaces

Boiler walls, precipitators, hoppers, ducts & flues, storage bins, etc.

Piping

Straight pipes, bends, elbows, accessories, fittings, valves, flanges, strainers, termination points, bevels, etc.

Instruments

Measuring and controlling devices for process requirements.

Height allowances

PRINCIPALS OF MEASURING EQUIPMENT

Shell - Cylindrical

The outside diameter of the vessel plus two times the insulation thickness multiplied by 3.14 and by the length of the tangent line to the tangent line as illustrated in the diagram. Transition sections (changes in diameter) shall be measured using the more significant diameter times the length. There shall be no deductions for manholes and any other interruption or projection, whether insulated or not.

Irregular Surfaces

Any irregular shape shall be measured outside the insulation surface using the largest diameter. The surface area for irregular surfaces shall be multiplied by a correction factor of 1.75 to obtain the equivalent area of a flat surface. For small pumps, turbines, etc., the minimum equivalent measurement area shall be 10 sq. feet.

Heads, Roofs, Ends

Flat: The surface area with a diameter outside of the vessel insulation.

Spherical: The hemisphere's surface area has a diameter outside the vessel insulation.

Dished: The surface area of a flat circle with a diameter outside the vessel insulation, multiplied by a correction factor of 1.37.

Cones: The geometrical surface area of the cone, measured outside the insulation thickness.

ADDITIONAL MEASUREMENTS

On "Unit Price" contracts, all insulated nozzles and manways connecting to a vessel will be measured as pipe runs to the vessel wall plus flange. In addition, all nozzles, manways, brackets, platform supports, obstructions, and penetrations shall have their perimeter measured as irregular surfaces. All penetrations shall be a minimum of 1 sq.

Foot per each.

On "Lump Sum" contracts, like obstructions, penetrations, nozzles, brackets, supports, stiffener rings, etc.

If they have not been shown in detail on bid drawings, they shall be measured, as above, as extra work to the contract.

PRINCIPALS OF MEASURING

Piping

The pipe shall be measured from the center line to the center line through all fittings, as shown in Diagram 'A,' Page 10.

All fittings will be counted and classified for multiplication by the appropriate factor listed in the "Fitting Factor Tables" on Pages 5 to 8. Fittings connecting two or more different pipe sizes shall be the most significant.

Bent Pipe: Shall be measured on the outside radius of the bend(s),

Traced Piping: Insulation sized to accommodate tracer(s) shall be measured at the actual size of insulation used.

Tracer loops shall be measured separately.

End of Section

Summary

The above information is a snapshot in time of the performance of the inspected insulation systems. Why is mechanical insulation one of the most overlooked and undervalued energy efficiency concepts within engineered building facilities in America? There are multiple reasons, but perhaps the most common cause is how facilities are contracted to be built in the U.S. Most buildings are designed. Then, the project owner requests that general contractors bid on the project. The General Contractor then makes bid documents available and solicits bids from contractors. The bid package includes drawings, specifications, general information, dates and times for submission of bids, and details as to whether the bid opening will be public or private. Specifications are usually provided using the Construction Specifications Institute's (CSI)'s, MasterFormat for construction. This breaks down specifications for commercial and industrial projects in the U.S. and Canada into 16 major divisions. These divisions include Site Works, Concrete, Doors and Windows, Finishes, Equipment, Mechanical/ Plumbing, and Electrical. The Mechanical & Plumbing Contractors that wish to bid on the project will solicit subcontractor bids from multiple subcontractors, including Mechanical Insulation subcontractors.

The scope of work for mechanical insulation is bid as part of the mechanical and plumbing system packages. The mechanical contractors solicit bids from several mechanical insulation subcontractors to find the lowest cost bid. Many public projects are statutorily bound to select contractors with the lowest bid price. As the mechanical and plumbing scopes of work will usually be awarded to the lowest cost mechanical system bid, it is in the mechanical contractor's best interest to choose the lowest mechanical insulation bid. (This strategy increases the likelihood that their entire mechanical bid will be selected).

After the General Contractor selects the Mechanical and Plumbing Contractors and contracts are signed, the Mechanical and Plumbing contractors will often then go back to their mechanical insulation contractors and "shop" or "buy out" the mechanical insulation portion of the project, asking the mechanical insulation contractor to find ways to reduce their bid price. This often leads to mechanical insulation contractors, looking for any "loopholes" in the specifications, where they can provide an alternative product, insulation with a lower performing thickness or "value engineering" out part of the original scope of work.

During construction installation, there are few instances in which the mechanical insulation systems are properly inspected prior to sign offs for payment of the mechanical and plumbing systems. It is easy for a mechanical contractor to "roll the dice" with selection of mechanical insulation contractors, regardless of their quality of work, adherence to the specifications, and sometimes their safety record. If the insulation installation is substandard or if the insulation contractor has not installed the correct thickness of insulation specified, the cost of correcting the improper installation is usually borne by the insulation subcontractor, and not the mechanical or plumbing contractor, so there is little incentive in today's marketplace to select the most qualified, best performing mechanical insulation contractor.

Mechanical insulation systems are unlike most other building systems. If an electrical system is not correctly installed, lighting will not illuminate, or some equipment will fail to energize. If the plumbing system is not correctly installed, water will not reach its destination or a drain will fail to function. If the mechanical insulation system is not correctly installed, the other systems will continue to function, however due to the lost energy, the facility owner may pay more than the original entire initial installation cost of the mechanical insulation portion of the project, sometimes every year, for the life of the building. As the contract to build the facility is often based on the lowest initial cost of the project, cutting costs on the initial mechanical insulation system installation is a prevalent practice.

An immense amount of misguided justification exists for reducing the best-performing mechanical insulation systems to reduce initial system installation costs. Examples include statements such as: “We are leaving off the insulation on all valves, pumps, and flanges so that the maintenance workers have free access for any repairs”. “Any heating that rises from these systems will simply heat the upper floors of the building”. “The systems in the tunnels are below ground, so only minimal insulation is needed”. “The systems in the chases are short runs, so installing insulation in them isn’t worth the money”. “We don’t have enough space or room to install thicker insulation in these areas of the building”. All of the previous excuses or justifications usually cost the owner significant amounts of money and are major sources of lost energy.

In the industrial setting, mechanical system insulation is left off systems for many reasons. As the mechanical insulation is one of the last items installed during a shutdown prior to “going back online”, if there are cost overruns on the piping, equipment, scaffolding, or time delays, often the mechanical insulation scope is reduced to “recapture some of the cost overruns”. Due to schedule delays, the owner will frequently make any possible cuts so that the remaining schedule can be compressed. The Outage manager will be under pressure from “Upper Management” to “get back on schedule” to manufacture the product.

The Maintenance or Facility Director often receives input from their maintenance team, requesting mechanical insulation be left off joints, flanges, valves, strainers, etc., to provide “easier access” when repairs are needed. However, this “ease of access” usually comes at reduced system efficiency, sometimes reducing the amount of “higher margin product production.” The cost of the energy lost, even for a short duration, is more than offset by the reduced efficiencies and the higher cost of additional fuel consumption.

Improving the performance of your MIS not only enhances the performance of your other mechanical systems but also results in lower life cycle costs for the other building systems. Boilers and Chillers operate at better efficiency levels, cycle less often, and use fewer chemicals to operate these systems. With less cycling, equipment such as pumps and their associated bearings and impellers last longer, there is less system downtime for replacements, your maintenance crew can attend to other duties, improving your facilities' systems performance.

Mechanical Insulation is an excellent investment. An integrated maintenance plan for mechanical insulation with actionable inspections protects your investment, improves your facility, and provides a plethora of benefits.

Mechanical Insulation Evaluations Collection Data

Performed in Houston, Texas
The systems referenced in this report were visually inspected while using a FLIR Model E-60 Handheld Infrared Camera and an Extech Instruments 5-in-1 Environmental Meter Model 45170CM to collect data.

We used the following data;

Cost of Natural Gas: $ 4.035 MMBtu /$ 0.370707 MMBtu
Cost of Electricity: $ 0.118 per KWH
Hours of Operation for Hot Water Heating System: 8700
Hours of Operation for Chilled Water System: 8700
Hours of Operation for Domestic Hot Water System: 8700
Hours of Operation for Food Service Recovery System 8700
System Temperatures:
Heating Hot Water: 190°F / 180°F
Chilled Water: 39°F / 50°F
Domestic Hot Water: 150°F / 145°F
Food Service Recovery 49°F
Wind Speed: >1 MPH
The Mechanical Insulation Review was performed by:
James A. Petrides CEM, CEA, CTII, CIEA
Tools Used to conduct/ collect data for the MIS Evaluation
Flir Model E-60 64501 CE0682
Extech Instruments Environmental Meter 45170CM

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