The Gas Company
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CODE CHANGE PROPOSAL

2005 Title 24 Building Energy Efficiency Standards Update

Gas Cooling Compliance Options for Residential and Non-Residential Buildings

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Overview

Natural gas cooling systems typically utilize an absorption cycle or engine-driven gas refrigeration cycle to produce a cooling effect, providing an alternative-cooling source to electricity. Natural gas fuel supplies are typically more abundant than electricity supplies in the summer cooling months due to the use of underground field storage facilities and, unlike electricity, natural gas demand normally peaks in the winter months. Also, distributed as opposed to central combustion eliminates transmission losses that accompany the supply of electricity.

There are two primary categories of gas cooling systems: engine-driven chillers and heat pumps, and gas-fired absorption cooling systems[1]. Five OEM manufacturers of gas engine-driven chillers and two manufacturers of heat pumps have been identified to date. Other similar products are under development and should be available in the market in the near future. Other types (non-absorption cycle) gas-fired or heat activated systems are also under development and may also be available in the foreseeable future.

On the commercial side, engine-driven chillers with reciprocating compressors are available up to 200 tons, screw compressors up to 1000 tons, and centrifugal compressors up to 6000 tons. There are about seven manufacturers of large gas absorption equipment up to 2600 tons. Two manufacturers, Mitsubishi and Goettl, make gas engine heat pumps. Goettl manufactures 15 and 20-ton heat pump units, and Mitsubishi manufactures smaller multiple zone split-system heat pumps (11 and 16 ton) that operate with multiple fan coil units, each with a TXV. In the residential sector there are at least two manufacturers of absorption chillers; both produce chilled water for split-system hydronic cooling applications. There are currently two manufacturers of large residential engine-driven heat pumps (Goettl and Mitsubishi).

The proposed application of time dependent valuation (TDV) of electricity in California energy standards will favor natural gas cooling, which yields a large electrical peak demand reduction compared to electric cooling. At a time when commercial on-peak rates are over 70% greater than off-peak rates and on-peak demand charges are more than 5-fold greater than off-peak demand charges[2], cooling technologies which nearly eliminate on-peak electrical use should appear attractive to developers and operators of commercial projects. Similarly, residential gas cooling customers on time-of-use rates should see substantial benefits.

Currently, only gas absorption cooling is represented in the Non-Residential Energy Standards and Alternative Calculation Method Approval Manual[3]. Engine-driven chillers and heat pumps are not described, nor is any form of gas cooling described in the residential Energy Standards or ACM manuals. It is possible to model several non-residential gas cooling system types using current ACM's and applying "professional judgement", but default input assumptions are not representative of the performance characteristics of available equipment. DOE-2, the performance model behind the ACM's, cannot simulate variable speed engine-driven systems such as the Mitsubishi heat pump.

There is also a conflict in standards and non-residential ACM language related to heat recovery. The standards appear to not allow heat recovery (such as for exhaust-fired absorption chillers), while the Non-Residential ACM Approval Manual does under limited circumstances.

The only gas technology that can be modeled using the residential ACM's (MICROPAS, CALRES, EnergyPro) is a gas engine heat pump. This model was developed for the now obsolete York Triathlon[4], but COP values may be entered to model other residential heat pumps[5]. Currently, only absorption air conditioners are available for small

[1] Absorption cooling systems can also utilize hot water, steam, turbine exhaust or any other heat source to drive the cooling cycle. Another technology that could fall within the definition of gas cooling is a steam turbine-driven chiller manufactured by York.

[2] PG&E Rate Schedule E-19, March 4, 2002; SCE Rate Schedule I-6, June 3, 2001.

[3] The Standards list minimum efficiencies for single and double effect absorption chillers only.

[4] The York Triathlon, developed by Battelle Laboratories for GRI.

[5] MICROPAS calculation methods use a temperature bin approach that should be replaced with more accurate hourly simulation methods.

residential applications. For larger residential applications (15+ tons), gas engine driven chillers, heat pumps or double-effect absorption chillers can be used.

This initiative will develop and improve ACM methods and propose standards enhancements, and will establish minimum performance criteria to be used for compliance. Adoption of an appropriate TDV method in compliance calculations will provide a more level playing field between electric and gas cooling technologies.

Description

The proposed change modifies standards and ACM Approval Manual language to explicitly include gas cooling as a compliance option. The change affects all building types covered by the residential and non-residential sections of the California Building Energy Efficiency Standards, and would most likely be applicable to commercial and single family residential occupancies.

Benefits

Gas cooling can provide substantial utility cost savings relative to electric cooling equipment, especially when time-of-use rates are applied. Although gas cooling does not always save site energy use, it can play a significant role in reducing generating capacity needs and offers substantial energy cost savings in the particular applications described below.

In specific applications gas cooling equipment can produce large energy savings relative to electric chillers due to their ability to be used in "combined" applications that generate waste heat that is used in other space conditioning processes. Since engine-driven heat pumps and chillers generate high-grade waste heat[6], they could be combined with indirect fired absorption equipment where the hot water or steam is generated from the waste heat. The recovered heat could also be used for domestic hot water.

Because absorption chillers do not require compressors, maintenance can be less than for compressor-based chillers, and they operate more quietly and with less vibration. Both absorption and engine-driven equipment can provide emergency cooling during power outages with minimal requirements for backup power, making them ideal for applications where maintaining comfort is critical.

Environmental Impact

All gas cooling systems produce emissions common to combustion equipment, including NOx, CO, SOx, miscellaneous hydrocarbons, and particulates. Gas cooling systems will cause increased emissions at the building site with some system types causing greater emissions than others. The level of increased gas emissions may or may not create a significant environmental impact depending on the significance of the expected impacts relative to air quality attainment in the local air basin. If there is a significant impact due to these increased gas emissions, it may be necessary for mitigation measures to be taken. Gas engine-driven equipment can be fitted with exhaust gas after treatment to reduce emissions and direct fired equipment can be fitted with low-NO_x burners. Heat recovery can also reduce net emissions; 45% of the gas energy used to operate an engine-driven chiller or heat pump can be recovered from the engine jacket and exhaust[7].

When gas cooling is installed in place of electric cooling that would have otherwise been installed, there will be lower demand on the electric power system. As a result emissions could be reduced on the marginal power plant in the system. However, predicting with accuracy which power plant(s) would be the marginal plant and therefore what the extent of the emissions reduction would be and where that emissions reduction would take place is speculative at best. California is provided with electricity through the Western U.S. regional electricity system. This is a highly

[6] Engine jackets produce 200°F water, and exhaust heat recovery produces 230°F water or low-pressure steam.

[7] American Gas Cooling Center publication (www.agcc.org/EngineBasics.htm)

complex, inter-connected system which is driven by variations in demand due to weather and the energy use patterns of people and businesses served by the system, by the existence of power contracts, planned and unplanned power plant maintenance, and on the margin by merchant plants located in or outside of California that can offer to sell power into or outside of California depending on the economics of the moment. This creates a situation where it is far from straight forward to relate potentially reduced emissions somewhere in the Western regional electricity system with expected increases at the building site where the gas cooling will be installed. A conservative analysis of the impacts of gas cooling will address the increased emissions due to increased natural gas cooling regardless of the potential for reduced emissions somewhere in the Western electricity system due to decreased electric cooling. The subject of emissions from gas cooling is being studied and will be presented in a supplemental report that is being prepared in support of the EIR process.

Since absorption chillers do not utilize CFC's or HCFC refrigerants, their potential to contribute to ozone depletion at the building site may be lower than that for electric chillers.

Another potential environmental impact is increased noise, particularly for engine driven gas cooling equipment. Initial data from manufacturers indicate that Absorption equipment will have comparable noise levels to electric equipment, slightly lower in some cases. For the engine driven equipment in commercial applications, the same mitigation measures taken for electric equipment (sound walls and interior mechanical rooms) will serve to reduce noise pollution levels to comply with local ordinances.

Type of Change

The proposed change adds new residential compliance options for absorption chillers, and improves compliance procedures for non-residential compliance options. Specifically this change would enhance or add compliance methodologies for the following technologies:

Residential: Single and Double-effect, direct-fired absorption chiller

Non-residential: Double-effect, direct-fired, water cooled absorption chiller
Single and Double-effect, indirect-fired absorption chiller
Gas engine chiller
Gas engine heat pump

Absorption equipment is included in the Non-Residential ACM Approval Manual (Section 3.5.2.2), but is not mentioned in the Residential ACM Approval Manual. Gas engine driven heat pumps are covered by the residential, but not the non-residential ACM manual, and gas engine driven chillers are only covered by the Non-Residential manual. Therefore, it is necessary to modify the Non-Residential ACM manual to include both gas engine driven chillers and heat pumps, and the residential ACM manual to include the direct-fired absorption chillers.

Combined systems such as exhaust and water jacket heat recovery systems are covered under Non- Residential ACM Approval Manual Sections 3.5.2.4 and 3.5.2.5, respectively, but are not allowed in the Standards, therefore the Standards should be modified to correct this inconsistency. Also, MICROPAS is not capable of modeling variable speed gas engine systems; changes to accommodate them will require specific exceptional method applications and later ACM manual additions. These changes will not be covered in this proposal

In summary, modifications to Standards include equipment/system definitions, revisions to specifications for minimum performance standards, and inclusion of energy recovery. Changes to the ACM manuals include provisions for modeling absorption and gas engine cooling systems. Residential and non-residential compliance manuals will also require revisions consistent with these changes.

Technology Measures

Measure Availability and Cost

Gas cooling products are readily available through many HVAC suppliers. Larger manufacturers such as Trane, Broad, McQuay, Carrier, Tecogen, York, and Mitsubishi have substantial manufacturing capacity. The smaller companies, such as Cooltech and Robur-Servel, which manufacture residential systems are in earlier production stages and are currently at low production volumes. Some companies, such as Ambian Climate Control will introduce products in the next few years. Since gas cooling is not a mandatory measure the increase in demand will be slow, providing time for manufacturers and suppliers to ramp up production and distribution. Competing products include conventional electric-powered air conditioners, package units, and electric chillers. Survey work is needed to accurately identify comparative installation and maintenance costs for gas-cooling and comparable electric cooling systems, but installed costs per ton are generally higher for gas cooling. Performance verification and commissioning costs should be nearly identical for gas and electric technologies.

Useful Life, Persistence and Maintenance

Based on available information, the useful life and maintenance requirements for absorption cooling systems are comparable to that of baseline electric systems. The fact that absorption chillers have fewer moving parts than compressor-based chillers suggests less maintenance would be required for these systems. Manufacturers' estimates of equipment life range from 15 to 30 years.

Maintenance costs for engine driven chillers are typically $.01 greater per ton-hour than for electric chillers[8]. This is primarily due to additional maintenance required by the engine; i.e. oil changes, tune ups, filter changes, etc. Tecogen projects a 25-year equipment life. Engine driven equipment require a major overhaul or engine replacement about halfway through the useful life of the equipment.

With the exception of potential replacement due to maintenance issues or excessive noise, energy and demand savings for gas cooling equipment are expected to be highly persistent. Performance degradation should be no greater than for baseline systems, and no more dependent on commissioning or performance verification. As with the baseline systems, equipment failures typically result in total loss of function, rather than the degradation of performance.

Performance Verification

Like electric cooling products, gas-cooling products undergo factory quality control inspections and testing, and should not require field performance verification other than typical commissioning. For newer equipment that is less familiar to installing contractors, commissioning is of added importance.

Cost Effectiveness

Economic comparisons of gas cooling technologies versus conventional electric cooling technologies indicate that gas engine chillers and absorption cooling can be cost effective in many applications, particularly if TDV conversion factors are used. Factors affecting cost-effectiveness include installed cost, cooling system effective performance, the ratio of gas to electric costs, and utilization of heat recovery. By virtue of their high heating efficiencies, engine driven heat pumps also can be cost effective when both heating and cooling energy is considered.

[8] Tecogen estimates an incremental maintenance cost of $.015 per ton-hour.

Analysis Tools

Residential

Currently the residential ACM's simulation of gas cooling technologies is limited to gas engine heat pumps. Since the residential ACM's are not capable of modeling gas absorption systems, this study applied the currently approved MICROPAS program's hourly output to a modified version of the TDV spreadsheet that includes gas cooling performance equations based on DOE 2.1E[9]. To accommodate existing residential gas cooling technologies, required enhancements to the compliance models will include the addition of equations to calculate hourly gas (and electric) energy use as a function of outside air temperature and part load. Changes to include gas cooling will need to be made consistently with proposed residential computer modeling assumption changes and the hourly electric air conditioner model and TDV multipliers that are proposed to be incorporated into the residential ACM's.

Non-Residential

EnergyPro 3.1 and its DOE-2.1E simulation engine were used to develop the non-residential energy savings data for this proposal. Modeling capabilities and problems encountered are described below.

Modeling Capabilities and Limitations

EnergyPro can model the following gas cooling options:

"SYSTEMS":
- Gas engine heat pumps (non-residential)

"PLANT":
- Gas engine chillers (water cooled)
- Double-effect direct-fired absorption chillers (water or air cooled)
- Single-effect indirect-fired absorption chillers (240°F water or 12 lb. steam)
- Double-effect indirect-fired absorption chillers (400°F water or 125 lb. steam)

Modeling Problem

When EnergyPro is applied to compliance calculations for gas absorption chillers, the electric input ratio (E-I-R) input in DOE-2 appears to result in double-counting of the electric power. This anomaly is apparently a bug in DOE-2 and is being researched.

Relationship to Other Measures

The proposed change would establish procedures for allowing gas cooling compared to the existing standard design. Therefore, no other measures are impacted by this change.

Acknowledgments

Southern California Gas Company (SCG) sponsored this code change proposal. Participating SCG personnel included Lance DeLaura and Randall Higa. A.Y. Ahmed of Occidental Analytical Group managed the project for SCG. Davis Energy Group led the development of this proposal, and Gabel-Dodd/EnergySoft subcontracted to provide a review of software capabilities and assisted with the non-residential analysis. Steve Brennan managed the

[9] This analysis will need to be revised once updated versions of MICROPAS are available which include all proposed computer modeling changes.

survey of manufacturers conducted by Patricia Teufel and completed the residential analysis. Bill Dakin completed the non-residential analysis. David Springer managed the project for Davis Energy Group.

Manufacturers of gas cooling equipment are the key stakeholders, and provided performance, cost, and other data needed to complete this analysis. The most generous contributors to this information included Goettl, Tecogen, Broad, Trane, Yazaki, Mitsubishi, Robur, and Cooltec.

Methodology

General Approach

The primary objective of analysis completed for this proposal was to determine how the application of TDV methods affects comparative energy use relative to the electric cooling baseline systems. To accomplish this, hourly models were used to evaluate gas cooling TDV energy use and compared to electric cooling TDV energy use in five climate zones. The hourly modeling used in these analyses is counterpart to the new hourly modeling approaches used for residential and non-residential electric cooling equipment.

The sole residential gas cooling technology currently available is an air cooled single-effect absorption chiller. Cooling is accomplished by circulating the chilled water through an air handler or furnace with a chilled water coil (instead of a DX coil). Current residential ACM's do not accommodate gas absorption cooling. A combination of DOE-2 performance curves and manufacturers' performance data were used to develop performance equations, as described in the sections that follow. To assure conservative results, "worst case" performance values were applied.

For the non-residential analysis, gas cooling TDV energy use was determined by evaluating each of the three common gas cooling technologies using EnergyPro. For engine-driven technologies, the current underlying DOE-2 default performance maps were not modified because complete performance data were unavailable from manufacturers. For commercial gas absorption cooling, a comparison with default DOE-2 performance values showed that the manufacturer's performance maps result in greater energy use than default DOE-2 performance maps. For this reason, the more conservative manufacturer's curves were applied to the DOE-2 engine used by EnergyPro, and are recommended for use in the new ACM methods.

Absorption units that use hot water, steam, and exhaust heat as their energy source are very specific in application, and require identification of the performance of the equipment that is used to generate the waste heat, and the loads imposed upon them. For these reasons, systems utilizing waste heat recovery were not included in this analysis and are not proposed for compliance credit[10]. However, systems relying on waste heat are likely to perform better than direct-fired systems.

Data Collection

Web searches, literature review, and supplier contacts were used to identify available gas cooling equipment. A questionnaire was developed (see Appendix) to obtain data on performance, cost, maintenance, and equipment life. Additional requests went out for noise and emissions data, including potential mitigation measures. The questionnaire mailing was followed up by phone calls until the necessary data were obtained[11]. Manufacturers of commercial equipment surveyed include Alterdyne, Broad, Goettl, Tecogen, Trane, Yazaki, Thermax, Mitsubishi, York, Kodiak Mechanical, Dunham-Bush, Carrier, McQuay, and LG Machinery. Cooltec and Servel-Robur were the only two residential manufacturers identified and surveyed. Ambian Climate Control (formerly GAX LLC) was also contacted but will not have their two-stage absorption unit on the market until 2003. Note that additional data

[10] Exception: Systems recovering heat from space conditioning equipment and that provide space conditioning and/or water heating. Examples are gas engine chillers that apply exhaust heat to an exhaust-fired absorption chiller, and gas engine chillers that use engine jacket water to heat water for space heating or domestic hot water.

[11] Very few manufacturers responded with all of the information requested.

collection will be necessary to conduct further environmental analysis of emissions impacts, noise impacts and mitigations to significant emissions or noise impacts.

Evaluation

Because different ACM's are used for residential and non-residential compliance, methods differed for residential and commercial systems. Analyses were completed for representative climate zones, including 6, 10, 12, 13, and 14. Commercial technologies evaluated included direct-fired double-effect gas absorption chillers, and gas engine-driven chillers and heat pumps. The sole residential technology evaluated (and currently available) was the air cooled, single-effect absorption chiller, which is represented by two manufacturers. Details of residential and non-residential evaluation methods are described in the following sections.

Residential Absorption Air Conditioner Analysis

The CEC standard 1761 ft^2 house was used as the basis for the residential analysis. The baseline (standard) case assumed electric cooling with an SEER of 12. Because the fully implemented TDV version of Micropas was not available at the time this work was completed[12], it was necessary to calculate TDV energy by using MICROPAS Version 6.1 to generate loads data. The loads data were then applied to the "TDV Spreadsheet" obtained from Heschong Mahone Group to determine TDV energy. This spreadsheet incorporates the electric cooling performance maps proposed to be included in the 2005 standards. Proposed changes to the residential ACM that affect cooling load were not accounted for in this analysis but could favor gas cooling technologies. For example, changes to the natural ventilation schedule are likely to increase on-peak cooling load.

The proposed method for calculating electric air conditioner energy use uses two performance parameters, EER and SEER, to calculate performance at varying outdoor temperatures. The method assumes that efficiency varies linearly with temperature between full load efficiency (EER at 95°F outdoor temperature) and part load efficiency (SEER at 82°F outdoor temperature). This approach makes it possible to ignore sizing (and part load) in the calculation of performance, and is different from the method used by DOE-2, which applies a part load function.

Since only one performance parameter is available for absorption chillers, (the COP at 95°F), it was not possible to apply the approach used for electric cooling to gas cooling. Instead, it was necessary to apply the DOE-2 approach, which calculates performance modifiers for outdoor temperature and part load. To accomplish this, "worst available" performance data were used to develop a curve that relates efficiency to outside air temperature. Since manufacturers could not supply part load performance data, a default DOE-2 equation for absorption chillers was used to modify performance based on part load. Since sizing is critical to this calculation, the proposed model conservatively assumes that the chiller is sized to the next highest half ton over the highest hourly load calculated by the ACM loads model.

There are two "parasitic" electric loads associated with residential absorption chillers, the outdoor unit (including fan, solution pump, and chilled water pump), and the indoor unit fan. Data on the former is readily available from manufacturers. The same indoor unit fan energy assumption was applied as has been proposed for electric cooling (153 W/ton).

Detailed methods used to determine site energy use for each climate zone from Micropas hourly loads and outdoor temperatures were as follows:

1. Cooling load and outdoor temperature data were extracted from the Micropas MPL files. The maximum load was also identified to serve as a basis for equipment sizing.

[12] Gas cooling performance curves would have had to be added to the model for it to be usable for this purpose.

2. Gas absorption unit cooling capacity (CAP) was calculated for each hour from the corresponding outdoor temperatures using Equation 1. Equipment sizes were established for each climate zone by rounding up to the nearest 0.5 ton greater than the maximum load.

$$\text{Hourly Capacity} = (CAP) \times (-0.00075(T)^2+0.13555T-5.10683)(kBtuh) \qquad \textbf{Equation 1}$$

where T = outdoor temperature in °F

This equation was derived by applying a polynomial fit to manufacturer's data (Robur). Because the lowest temperature for which data were available was 90°F, the capacity was assumed to be constant below 90°F (the same as the capacity at 90°F).

3. The part load ratio (PLR) was calculated for each hour using Equation 2:

$$PLR = \text{Hourly Load} / CAP \qquad \textbf{Equation 2}$$

4. The temperature-adjusted full load instantaneous efficiency (COP-T) was calculated for each hour as a function of outdoor temperature using Equation 3:

$$COP\text{-}T = (-0.00665285T + 1.243212) \qquad \textbf{Equation 3}$$

This equation was also obtained using a polynomial fit of manufacturer's data (Robur)[13]. The value of COP-T was also assumed to be constant below 90°F.

5. The HIR (heat input ratio) was calculated by taking the inverse of the COP:

$$HIR = 1/COP \qquad \textbf{Equation 4}$$

6. The HIR adjustment factor for part load (HIR-PLR) was calculated using Equation 5. This factor accounts for performance degradation resulting from cycling, and was obtained from the DOE-2 gas absorption chiller model.

$$HIR\text{-}PLR = 0.24651277(PLR)^2 + 0.61798084(PLR) + 0.1355115 \qquad \textbf{Equation 5}$$

Unless $PLR < 0.1$, then $HIR\text{-}PLR = 2(PLR)$

The second part of the equation was added to prevent the fuel consumption from "blowing up" at low part loads, and to reflect the fact that the minimum runtime will not likely be less than 6 minutes given the warm-up time of the equipment.

7. The part load modified HIR was calculated by multiplying the HIR by the HIR-PLR from Equation 5.

8. The modified HIR was multiplied by the capacity calculated using Equation 1 (for each hour) to determine the gas energy consumption.

[13] Of the two residential systems, the Robur unit has lower performance.

9. Total energy use for each hour was calculated by multiplying the Absorption Chiller power consumption (1000W, including condenser fan, solution pump, and chilled water pump) by the part load ratio, and adding the indoor unit fan power (153W/ton).

Gas energy consumption values from the analysis spreadsheet were then inserted into the gas energy use column of the MPL files and the electrical cooling energy use data erased. The TDV residential spreadsheet was used to compare the "Standard Design" to the "Proposed Design" for each of the five climate zones. Total electrical energy use was calculated by multiplying full-hour electric use by the part load ratios for each hour; results were inserted into the "Fan Wh" column on the Proposed Design sheet of the TDV spreadsheet. The total cooling electrical energy column had to be modified to exclude the electric cooling load that the spreadsheet automatically calculates.

Factors to degrade performance that are used in the proposed electric air-conditioning calculation, including inadequate refrigerant charge (which is not applicable to absorption cooling) and low airflow were not included in the gas cooling calculations. However, the use of the temperature-based performance curve from the "worst available" technology, and the half-ton over-sizing make this analysis conservative. As described in the Proposed ACM Language Changes, we also propose to further depreciate the COP-temperature curve. The same approach to calculating sensible plus latent load and duct heat gain as used by the electric cooling model would be applied for gas cooling.

Additional analysis details are provided in the Results section. Compliance comparison summary sheets are in Appendix D.

Non-Residential System Analysis

General Approach

The current non-residential compliance method is able to quantify energy savings and peak demand reduction for the proposed non-residential technologies. Aside from the TDV enhancement, only minor modifications to the compliance method were necessary to model the non-residential gas cooling equipment. These modifications are outlined in the following Gas Engine Heat Pumps, Gas Engine Chillers, and Double-Effect Gas-Fired Absorption Chillers sections. EnergyPro was used to develop the energy savings data for the current analysis[14]. A 7,200 sq. ft. office building, developed by Gabel Dodd/EnergySoft for non-residential ACM tests, was used for comparing all gas cooling technologies.

EnergySoft developed the initial "proposed" and "standard" models for each of the non-residential gas cooling technologies. Proposed input files for gas engine heat pumps were modified to accommodate equipment performance values obtained from surveys, and for other reasons discussed. The only inputs that EnergyPro allows for compliance runs include HIR (or COP), EIR, electric parasitic and fan power inputs. Analysis of each of the technologies was completed as described in the following sections.

Gas Engine Heat Pumps

The EnergyPro package single zone system model was employed for gas engine heat pump analysis. The baseline (standard) model assumes a package air conditioner with gas heat. The heating source command for the proposed option must be specified as a gas heat pump. Modifications to the proposed input files were necessary because the input files provided by EnergySoft had the following differences that were not applicable to the technology.

1. Cooling and heating efficiencies were revised to be consistent with manufacturers' values
2. Electric (parasitic) power was input for the gas heat pump

[14] An exception is that the default absorption chiller performance curves used in the DOE-2.1E engine used by EnergyPro were replaced with more conservative manufacturer's curves.

These two items may require revisions to the compliance software in order to work properly. Manufacturer's heating and cooling efficiencies were input into EnergyPro. Auxiliary electric power input into EnergyPro was not reported in output files as auxiliary power but as "OUTSIDE-FAN-ELECTRIC".

The following inputs were based on the manufacturers' data for the Goettl 20 ton heat pump. These inputs were entered into EnergyPro without modifying the DOE2 default curves. See Appendix F for a list of inputs, both from manufacturers' data and DOE2 defaults:

HEAT-SOURCE	= GAS-HEAT-PUMP	
SUPPLY-KW	= 0.000549	- Fan power - 8000 CFM / 5 hp motor
COOLING-HIR	= 1.657	- Cooling Heat Input Ratio (= 1/COP or Gas Input/Cooling Output)
HEATING-HIR	= 1.382	- Heating Heat Input Ratio (= 1/COP or Gas Input/Heating Output)
UNIT-AUX-KW	= 3.4	- Auxiliary power

Gas Engine Chillers

No modifications to the EnergyPro DOE-2 input files provided by EnergySoft were necessary to model gas engine chillers. A variable air volume system with a central chiller was specified for this option. The base case system uses a reciprocating chiller with an EIR of 0.2242 (~0.78 kW/ton), and a water-cooled condenser and cooling tower. Space heating systems for both standard and proposed runs were identical. A 40-ton, water-cooled, gas engine chiller was specified to match the building loads. Since manufacturer' information was not available for equipment this small, the ratio of parasitic power to capacity for 150-ton equipment was used. Performance data for a Tecogen 150 ton chiller were used to develop the following inputs. See Appendix F for a list of inputs, both from manufacturers data and DOE2 defaults:

TYPE	= ENG-CHLR	
SIZE	= 0.480	- MMBtuh
E-I-R	= 0.00373	- parasitic power ratio taken from 150 ton equipment
ENG-CH-COP	= 1.4	- DOE-2 default. Corresponds to typical value for Tecogen models

Double-Effect Gas-Fired Absorption Chillers

The evaluation of double-effect (two-stage) absorption chillers used the same system type as the gas engine chillers. The baseline (standard) model was also identical to the model used for gas engine chillers. Modifications to the proposed input file were necessary due to what is perceived to be a bug in the DOE-2 program. The electrical consumption value for gas absorption chillers reported in the output is twice the input value, which significantly penalizes gas absorption chillers. A 40-ton Yazaki gas absorption chiller was used for comparison. The inputs used the following DOE-2 commands. See Appendix F for a list of inputs, both from manufacturers data and DOE2 defaults:

TYPE	= ABSORG-CHLR	
SIZE	= 0.480	- MMBtuh

E-I-R = 0.00635 - 1790W Half of the value input to adjust for DOE-2 error

ABSORG-HIR = 1.0 - Heating input ratio. DOE-2 default.

Performance curves for efficiency versus leaving chilled water temperature and condenser temperature from manufacturer's tables were more conservative than the default curves, and therefore were used instead. These more conservative curves are proposed to be substituted for the current defaults in the ACM. Under current ACM rules, these performance curves are not allowed to be adjusted, therefore the most conservative values must be used.

Results

Results reported in this section are limited to a comparison of source energy use and TDV methods for gas cooling technologies and their corresponding standard electric technologies. No effort was made to calculate the net present value of gas cooling due to the lack of adequate data on installed costs. It should be noted that the compliance margins in these tables will allow some other aspect of the performance of the building (e.g., the building envelope, lighting system, etc.) to be degraded by the amount of the compliance margin and still comply with the Standards.

Residential Gas Absorption Chiller Analysis Results

The following results were generated using the 1761 square foot CEC Standard house. The model was run for climate zones 6, 10, 12, 13, and 14 and compared the baseline Standard Design (Electric A/C) to the Proposed Design (Gas Absorption A/C).

Table 1 compares the two technologies using the current method (flat rate multiplier of 10.239 kBtu/kWh) and Table 2 shows the results comparing the same two technologies using the Time Dependent Valuation method. Since heating and water heating energy use for the two cases was identical, only cooling energy is shown in Tables 1 and 2. However, compliance margins reported in the last column of these tables include both heating and cooling energy use. Appendix D includes complete comparison tables generated by the TDV spreadsheet.

Table 1: Residential Gas Absorption Compliance - Flat Source Multiplier

Climate Zone	Current Method: Cooling Source Energy kBtu/sf-yr		Compliance Margin
	Standard Design Cooling Energy Budget	Proposed Design Cooling Energy Use	
6	2.36	4.50	-10.0%
10	9.43	19.25	-30.0%
12	4.93	10.29	-14.6%
13	12.67	25.96	-32.6%
14	12.01	23.98	-26.1%

Note: Negative compliance margin values indicate non-compliance.

Table 2: Residential Gas Absorption Compliance - TDV Multipliers

Climate Zone	Time Dependent Valuation: kBtu/sf-yr		Compliance Margin
	Standard Design Cooling Energy Budget	Proposed Design Cooling Energy	
6	7.41	6.19	4.5%
10	27.24	25.25	3.9%
12	15.05	12.08	6.5%
13	29.08	28.15	1.6%
14	31.05	31.03	0.0%

Non-Residential Results

This section includes results determined using the same five climate zones as used in the residential analysis. Tables 3-8 report total heating and cooling energy use of the representative equipment being tested. *Proposed* and *standard* gas heating energy use was determined using the same heating equipment for both the gas-engine driven chiller and the direct-fired absorption chiller cases. Because the proposed and standard space heating budgets are different for gas-engine heat pumps, both heating and cooling energy use is reported in all the tables for consistency.

Gas Engine Driven Chiller

Standard energy use values listed in Tables 3 and 4 are based on a 40-ton electric reciprocating chiller. Proposed energy use is for the gas engine chiller described in the Methods section. The Table 3 comparison applies the flat source energy multiplier, and Table 4 applies the TDV multipliers.

Table 3: Gas Engine Chiller Compliance- Flat Source Multiplier

Climate Zone	Source Energy, MMBtu/yr		Compliance Margin
	Standard Design Energy Budget	Proposed Design Energy Use	
6	1,028.7	1,144.3	-11.2%
10	1,131.7	1,185.4	-4.7%
12	1,129.0	1,167.4	-3.4%
13	1,182.7	1,330.5	-12.5%
14	1,189.8	1,227.8	-3.2%

Table 4: Gas Engine Chiller Compliance- TDV Multipliers

Climate Zone	TDV Source Energy, MMBtu		Compliance Margin
	Standard Design Energy Budget	Proposed Design Energy	
6	2,094.3	1,992.7	4.9%
10	2,306.1	2,041.4	11.5%
12	2,022.7	1,857.8	8.2%
13	2,144.0	2,053.5	4.2%
14	2,327.4	2,060.8	11.5%

Double Effect Absorption Chiller

The same 40-ton electric reciprocating chiller was used as the baseline case for double effect absorption chiller analysis. Table 5 shows the comparison for the current source energy method, and Table 6 shows the comparison for the TDV method.

Table 5: Double Effect Absorption Chiller Compliance- Flat Source Multiplier

Climate Zone	Source Energy, MMBtu/yr		Compliance Margin
	Standard Design Energy Budget	Proposed Design Energy Use	
6	995.7	1,244.6	-25.0%
10	1,089.5	1,323.5	-21.5%
12	1,093.0	1,249.4	-14.3%
13	1,143.7	1,342.1	-17.3%
14	1,142.5	1,304.3	-14.2%

Table 6: Double Effect Absorption Chiller Compliance- TDV Multipliers

Climate Zone	Time Dependent Valuation: MMBtu		Compliance Margin
	Standard Design Energy Budget	Proposed Design Energy	
6	2,016.3	2,089.9	-3.7%
10	2,234.5	2,190.5	2.0%
12	1,967.4	1,955.3	0.6%
13	2,084.5	2,074.0	0.5%
14	2,247.0	2,155.4	4.1%

Gas Engine Driven Heat Pump

An 18.5-ton packaged A/C system was used as the baseline case for this analysis as is prescribed by the non-residential ACM manual for package single-zone systems. Table 7 shows the comparison for the current source energy method, and Table 8 shows the comparison for the TDV method.

Table 7: Gas Engine Driven Heat Pump Compliance- Flat Source Multiplier

Climate Zone	Current Method: Source Energy MMBtu/yr		Compliance Margin
	Standard Design Energy Budget	Proposed Design Energy Use	
6	1,185.4	1,221.8	-3.1%
10	1,413.2	1,517.6	-7.4%
12	1,335.0	1,377.1	-3.2%
13	1,467.3	1,574.9	-7.3%
14	1,483.9	1,539.8	-3.8%

Table 8: Gas Engine Driven Heat Pump- TDV Multipliers

Climate Zone	Time Dependent Valuation: MMBtu		Compliance Margin
	Standard Design Energy Budget	Proposed Design Energy	
6	2,628.6	2,234.0	15.0%
10	3,156.2	2,584.9	18.1%
12	2,646.2	2,230.0	15.7%
13	2,893.3	2,449.1	15.4%
14	3,304.3	2,671.2	19.2%

Summary of Results

In most of the cases evaluated results show that typical gas cooling systems consume less source energy under the TDV scenario than their standard electric cooling counterparts. Gas Engine Driven Heat Pumps produce large compliance margins, despite their performance using the current flat source energy multiplier.

Recommendations

This report recommends that available gas cooling technologies be recognized in the Standards and accommodated by the ACMs. Available technologies include residential absorption chillers (air source); and non-residential direct fired water cooled absorptions chillers, air- and water cooled gas engine heat pumps, and water-cooled gas engine chillers.

This proposal also recommends that Time Dependent Valuation (TDV) methods be used to evaluate gas cooling technologies, and that the baseline for performance analysis be comparable electric cooling systems. Changes to Standards and ACM Manual language related to time dependent valuation of energy are described in the code change proposal titled "Time Dependent Valuation (TDV) – Economics Methodology". Additional changes to the standards language listed below will be required after the hourly modeling and TDV language has been developed.

The current 2001 standards include non-residential gas absorption cooling, and no changes to the standards are necessary since the non-residential ACM's perform hourly simulations of plants and systems. Performance is currently calculated using default DOE-2 curves. A more conservative performance curve than the current HIR-temperature curve is proposed as an ACM revision for absorption cooling. This curve is consistent with manufacturers' data.

Although current standards do not address gas engine chillers and heat pumps, they are capable of being modeled by the ACM's. Therefore we propose the addition of minimum performance values to the standards tables. Lacking definitive manufacturers' performance data, we recommend no change to the default DOE-2 performance maps.

The residential ACM's are capable of modeling a gas engine heat pump that is no longer on the market. Compliance information on this technology should be removed from the ACM Manual, particularly since retaining analysis methods would require development of an hourly method.

Residential gas absorption systems are currently not recognized in the Standards or the ACM Manual, and we recommend they be added to both. Residential gas absorption cooling data reported in the Results section are based on manufacturer's performance curves relating COP to outdoor temperature. Equation 3.4gc (see Proposed Language – Residential ACM Manual), proposed for inclusion in the ACM Manual, applies a more conservative relationship that will result in greater energy use than that reported. This equation was derived by developing a linear fit of manufacturer's data for the system with the lowest efficiency (see Figure 1). The linear equation was then shifted down to correspond to a COP of 0.60 (.0217 lower than Robur) at rated conditions (95°F db outdoor air), which is the minimum allowable efficiency listed in Table 1-C3 of the Standards document for single effect gas absorption chillers. This more pessimistic curve is labeled "proposed default curve" on figure 1 below, and is intended to prevent poorer performing equipment from benefiting from a optimistic default efficiency curve. The actual data from the two manufacturers of this technology are also plotted on this graph, along with the linear fit curve for the Robur equipment, on which the default curve is based.

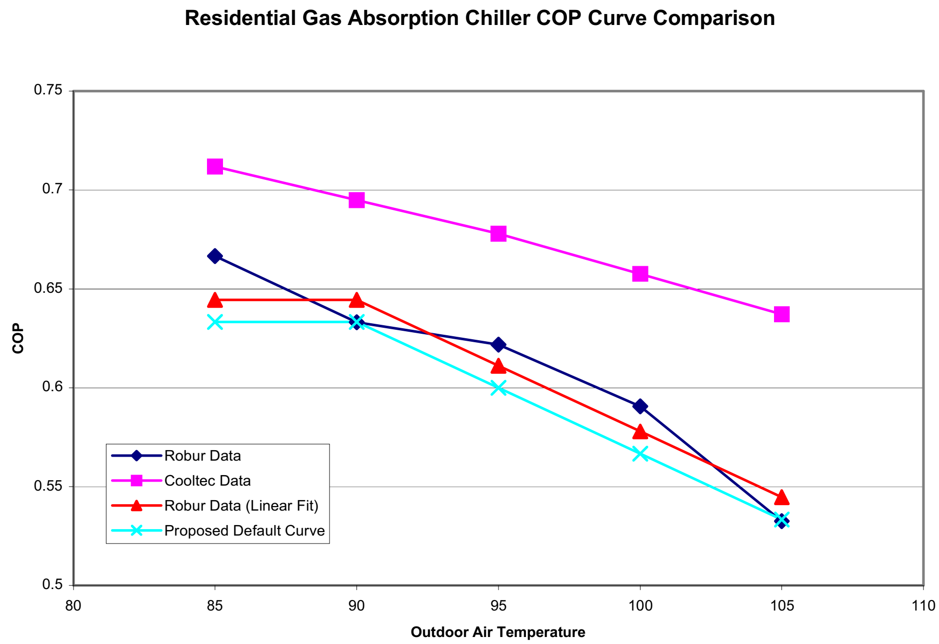

Figure 1: Residential Gas Absorption COP Curve Comparison

Proposed Standards Language Changes

Summary of Changes

1. Add definitions of the new equipment in the definitions section.

2. Modify title and add information to tables 1-C2 and 1-C3 to cover the minimum efficiency requirements for gas-fired cooling equipment. The proposed efficiency levels in these tables are the lowest levels that are commonly achieved by currently available equipment, and that use no more energy in TDV terms than standard electric equipment.

3. Modify Section 141 to include recovered energy from space conditioning when applied to building loads when calculating energy budgets.

Proposed Language

Section 101:

GAS COOLING EQUIPMENT is cooling equipment that produces chilled water or cold air using natural gas or liquefied petroleum gas as the primary energy source.

Section 112, Table 1-C2:

Table title:

TABLE 1-C2 UNITARY AND APPLIED HEAT PUMPS, ~~ELECTRICALLY OPERATED~~ MINIMUM EFFICIENCY REQUIREMENTS

Table changes:

Add the first row of data under the header into the table under the last (Cooling Mode) entry. Add the bottom row to the bottom of the table:

Equipment Type	Size Category	Sub-Category or Rating Condition	Efficiency	Test Procedure
Air-Cooled Gas-Engine Heat Pump (Cooling Mode)	All Capacities	95°F db Outdoor air	0.60 COP	ANSI Z21.40.4
Air-Cooled Gas-Engine Heat Pump (Heating Mode)	All Capacities	47°F db/43°F wb Outdoor Air	0.72 COP	ANSI Z21.40.4

Section 112, Table 1-C3:

Add the following line to the bottom of the table (header is included as placeholder):

Equipment Type	Size Category	Efficiency	Test Procedure
Water Cooled Gas-Engine Driven Chiller	All Capacities	1.2 COP 2.0 IPLV	ANSI Z21.40.4

Section 141 – Performance Approach: Energy Budgets

(c) **Calculation of Budget and Energy Use**. When calculating the energy budget under Subsection (a) and the source energy use under Subsection (b), all of the following rules shall apply:

1. **Methodology**. The methodology, computer programs, inputs, and assumptions approved by the commission shall be used.
2. **Energy included**. All energy, from depletable sources and recovered from space conditioning equipment, used for space conditioning, lighting, and service water heating shall be included.
3. **Energy excluded**. The following energy shall be excluded:

A. Process loads; and

B. Loads of redundant or backup equipment, if the plans submitted under Section 10-103 of Title 24, Part 1, show controls that will allow the redundant or backup equipment to operate only when the primary equipment is not operating, and if such controls are installed; and

C. Recovered energy other than from space conditioning equipment

D. Additional energy use caused solely by outside air filtration and treatment for the reduction and treatment of unusual outdoor contaminants with final pressure drops more than one-inch water column. Only the energy accounted for by the amount of the pressure drop that is over one inch may be excluded.

Proposed ACM Language Changes

Summary of Changes

Residential:

- Add minimum equipment efficiency/method mention under Standards Reports, Certificate of Compliance, HVAC systems
- Add new equipment (chillers) to table 2-3
- Add equations and modify language in section 3.8.2.

Non-Residential:

- Add section 3.5.2.3 for gas engine cooling equipment.
- Change default coefficients in the DOE2.1 tables.

Proposed Language – Residential ACM Manual

Notes: Specific language to describe TDV modeling, air conditioner sizing, and other proposed residential compliance changes has not been fully developed. Changes listed below document the calculations needed to convert hourly building loads into energy use values that, when TDV multipliers are applied, yield TDV energy. This language will require integration with other related language as it is developed.

Gas cooling methods should apply identical methods for adjusting building cooling load for duct heat gain and latent cooling load as used by electric cooling. Similarly, sizing methods should be identical to those required for electric cooling, but since they are potentially under revision, specific eligibility criteria related to sizing cannot be developed at this time[15]. The method proposed for electric equipment of sizing to the nearest half-ton larger than the calculated load is recommended for use with gas cooling compliance also.

Section 2.1 – Certificate of Compliance (page 2-15):

Minimum Equipment Efficiency/Method (fraction/recommended descriptor): The minimum equipment efficiency needed for compliance along with the applicable method.

Permissible Methods: *AFUE* for furnaces and boilers, *HSPF* for electric heating equipment, *SEER* for heat pumps (cooling) and central air conditioners, *COP* for gas-cooling equipment, and *RE* for water heaters

Section 2.1 – Certificate of Compliance (page 2-14):

GAbsorp Direct-fired, single-stage absorption chiller/air conditioner. Descriptors expressed as $COP_{coolinggas}$, $COP_{coolingelectric}$

Section 2.2 – Computer Method Summary C-2R (page 2-41):

• *Equipment Type.* The type of heating or cooling equipment. This is specified separate from the distribution type. Required heating equipment and cooling equipment entries are listed in Table 2-7Table 2-2 and Table 2-3. When the proposed house is not air conditioned, the entry should be NoCooling. If more than one type of equipment is specified, they may be listed on subsequent rows. If Gas Absorption equipment is specified, then it must also be

[15] According to Bruce Wilcox, proposed electric cooling sizing methods could be applied to gas cooling. The primary objective of the proposal was to reduce peak air conditioner load, which is not as strong an issue for gas cooling.

reported in the *Special Features and Modeling Assumptions* listings on the CF-1R and C-2R forms printed by the ACM.

Section 3.8.2 Cooling Equipment (page 3-16):

Proposed Design: ACMs must be able to model the basic types of cooling equipment listed in Table 2-43. ACMs must require the user to enter the basic information to model the energy use of these pieces of equipment. At the minimum this includes some type of seasonal distribution system efficiency for cooling, identification of whether the cooling system is ducted or non-ducted and central or non-central. For gas absorption cooling this includes the rated capacity and COP at 95°F db outdoor air, parasitic power consumption, and measured fan energy if available (otherwise default fan energy will be used). If the cooling system is non-ducted non-central, the ACM must require the user to select the type and size of the equipment from those shown in Table 3-6. The efficiencies of all electric cooling equipment and distribution systems are converted to source seasonal energy efficiency ratios (SSEER), as shown in Equations 3.2c and 3.3c. The efficiencies of all gas cooling equipment and distribution systems are processed through the hourly TDV model ~~converted to source seasonal efficiency~~ as shown in Equations 3.1gc – 3.7gc. ~~4c~~. Packaged air conditioning systems (PkgAirCond, LrgPkgAirCond, PkgHeatPump or LrgPkgHeatPump) shall be noted in the Special Features and Modeling Assumptions listings.

The hourly model for gas cooling utilizes the hourly load values and the hourly outdoor temperature values generated by MICROPAS to determine the gas energy consumption. These hourly values will be referred to as L_n and T_n in the equations below where the n represents the hour of the year. The user inputs will be denoted as follows:

CAP = Rated capacity at 95°F db outdoor air

$COP_{coolinggas}$ = Rated COP at 95°F db outdoor air

PPC = Parasitic Power consumption (W) at full load (outdoor unit only, exclude indoor fan power)

FE = Indoor Fan Energy (optional. Will default to 153W/ton unless user enters measured value in W/ton) If the actual fan energy is claimed, this shall be noted in the Special Features and Modeling Assumptions listings.

Gas absorption unit hourly cooling capacity is calculated from the corresponding outdoor temperatures using Equation 3.1gc.

$$CAP_n = (CAP) \times (-0.00075(T_n)^2 + 0.13555T_n - 5.10683) \times 1000 \qquad \textit{Equation 3.1gc}$$

Note: If $T_n < 90°F$ then $CAP_n = CAP \times 1.0177 \times 1000$ for hour n

The hourly part load ratio is calculated using the corresponding hourly cooling loads and capacities.

$$PLR_n = L_n / CAP_n \qquad \textit{Equation 3.2gc}$$

The hourly HIR part load adjustment factor (HIR-PLR) is calculated as a function of that hour's PLR.

$$HIR\text{-}PLR_n = 0.24651277(PLR_n)^2 + 0.61798084(PLR_n) + 0.1355115 \qquad \textit{Equation 3.3gc}$$

Note: If $PLR_n < 0.1$ then $HIRAF = 2 \times PLR_n$

The hourly COP is a function of that hour's outdoor dry bulb temperature.

$$COP_n = (-0.00665285T_n + 1.221512) + (COP_{coolinggas} - 0.60) \qquad \textit{Equation 3.4gc}$$

Note: If $T_n < 90°F$ then $COP_n = 0.6228+(COP_{coolinggas}-0.60)$

The hourly HIR is calculated by taking the inverse of the COP and multiplying by the HIR-PLR for that hour.

$HIR_n = (1/COP_n) \times HIR\text{-}PLR_n$ ***Equation 3.5gc***

Gas cooling gas energy consumption (GCGEC) is calculated by multiplying the HIR by the hourly capacity calculated using Equation 3.1gc.

$GCGEC_n = CAP_n \times HIR_n$ ***Equation 3.6gc***

Gas cooling electric energy consumption (GCEEC) is calculated as shown in equation 3.7gc.

$GCEEC_n = (PPC + FE \times ((CAP \times 1000)/12000)) \times PLR_n$ ***Equation 3.7gc***

Proposed Language - Non Residential ACM Manual

Note: Chiller performance curves inclusive in DOE-2 are not currently documented in the ACM manual, but are documented in the DOE-2.1E Supplement Update. An appropriate location to place proposed changes to those curves in the ACM must be determined. Changes proposed to the gas absorption chiller curves[16] are listed below, without reference to an existing section.

3.5.2.3 Gas-Engine Driven Chillers and Heat Pumps

Description: ACMs may model engine driven cooling equipment with the following features:

- *Engine Driven Chiller.* Fossil fuel engine driven, compressor water chiller.
- *Engine Driven Heat Pump.* Fossil fuel engine driven heat pump.
- *Air Cooled Condenser.* Chiller or Heat Pump uses air to cool condenser.
- *Water Cooled Condenser.* Chiller or Heat Pump uses water to cool condenser.
- *Engine Waste Heat Recovery.* Waste heat is recovered from engine coolant for reuse in a space heating or domestic water heating application.
- *Exhaust Heat Recovery.* Heat is extracted from engine exhaust gases for reuse for reuse in a space heating or domestic water heating application (see 3.5.2.4).

DOE Keyword: PLANT-EQUIPMENT
ENG-CHLR
or
HEAT-SOURCE
GAS-HEAT-PUMP
Input Type: Required
Tradeoffs: Yes
Modeling Rules for Proposed Design:
The ACM shall model gas engine driven equipment in the proposed design as input by the user according to the plans and specifications for the building. The ACM shall use performance relationships as established by the DOE 2.1 default equipment curves.
Modeling Rules for Reference Design (New):
ACMs shall determine the standard design according to the requirements of the

[16] Original curves were developed for DOE-2.1D with the collaboration of the Gas Research Institute and ElectroCOM GARD, Ltd.

Required Systems and Plant Capabilities and Figure 2-1.

Modeling Rules for Reference Design (Existing Unchanged & Altered Existing):

ACMs shall model the existing system as it occurs in the existing building. If the permit involves alterations, ACMs shall model the system before alterations.

Gas-Engine Driven Chillers and Heat Pumps

Replace the coefficients used in the default DOE-2.1E tables with the corresponding coefficients listed in the table below:

Keyword	Independent Variables	Coefficients (a)	(b)	(c)	(d)	(e)	(f)
ABSORG-HIR-FT	Leaving chilled	7.8242636	-0.132986	0.0031179	0	0	0
ABSORG-HIR-FT1	Condenser	11.519838	-0.2617834	0.0016238	0	0	0

Bibliography and Other Research

Other Research

A market assessment of gas cooling completed by Davis Energy Group for the Gas Company in 1987 provided background for the range of technologies available (DEG 1987). As part of this work DEG and Enercomp collaborated to produce TESCOGEN, a program that used a version of MICROPAS to generate building loads and a systems module to compute energy use for a variety of gas cooling technologies. Because of the need to employ current ACM's, TESCOGEN was not used to complete the analysis described in this report.

Much more recently the New Buildings Institute compiled an advanced design guideline for absorption chillers that was used as a reference for this report. The NBI report includes cost effectiveness graphs for multiple gas and electric rate scenarios and climate locations.

The American Gas Cooling Center (AGCC) was also used as a source of information for this report The AGCC web site (www.agcc.org) contains information on both gas absorption and gas engine technologies, including schematics, a review of applications, and other information. The Federal Energy Management Program (FEMP) website also includes applications and performance data on gas absorption systems. Both the NBI and the AGCC documents will be used to further investigate the need for additional eligibility criteria for gas cooling equipment compliance options.

Standards documents from the California Energy Commission were used in the creation of the "Proposed Language" section of the "Recommendations". The documents used were the 2001 AB970 Energy Efficiency Standards and the 2001 Residential and Non-Residential ACM manuals.

The ANSI and ARI standards were referred to in the "Proposed Language" section. These standards dictate the rated conditions for testing the gas cooling equipment to see if they meet minimum efficiency requirements and to generate the data necessary for compliance testing.

Manufacturers' test data must define test conditions for the data to be usable with confidence in modeling. Little manufacturer data could be located on part load operation, so the default values were used in DOE-2.

Bibliography

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ARI 2000. *Absorption Water Chilling and Water Heating Packages.* ARI Standard 560, Air-Conditioning and Refrigeration Institute, Arlington, VA, 2000

NBI 1998. *Absorption Chillers – Advanced Design Guidelines.* Design guidelines prepared for the Southern California Gas Company by the New Buildings Institute, Fair Oaks, CA, November 1998.

IAS 1996. *Performance Testing and Rating of Gas-Fired, Air Conditioning and Heat Pump Appliances.* ANSI standard Z21.40.4-1996, International Approval Services – U.S., INC, Cleveland, OH 44131

Appendices

Appendix A: Questionnaires

Appendix B: ACM Comparison Spreadsheets for the Residential Gas Absorption Air Conditioner

Appendix C: ACM Comparison Spreadsheets for the Non-Residential Gas Engine Driven Chiller

Appendix D: ACM Comparison Spreadsheets for the Non-Residential Double Effect Absorption Chiller

Appendix E: ACM Comparison Spreadsheets for the Non-Residential Gas Engine Driven Heat Pump

Appendix F: DOE2 inputs.

Appendix A: Questionnaires

General Questions

1. How long has the technology been on the market in its current form?

2. Approximately how many units have been produced and/or sold?

3. What is the estimated trade price, or what is the name of a distributor who can provide a current trade price?

4. What are the expected annual maintenance costs (as a percentage of initial equipment cost).

5. What is the expected equipment lifetime?

6. Please describe equipment performance by filling in a form we will fax to you. If you have equipment literature that includes the information we need, please mail it.   (Careful - they are likely to send sales literature when what we really want is engineering data.)

Gas Engine Chiller (Commercial)

Unit model number: ___________________________
Nominal tons: ________

Rating Conditions
Specify rating standard organization/number (if avail.) ______________
Engine RPM _______
Entering condenser water temperature ______°F
Leaving chilled water (evaporator) temperature _____°F

Capacity at rated conditions: _____________ MBtuh
Capacity at other conditions and rated RPM:
________ MBtuh at ______°F entering condenser temperature
________ MBtuh at ______°F entering condenser temperature
________ MBtuh at ______°F entering condenser temperature

________ MBtuh at ______°F leaving evaporator temperature
________ MBtuh at ______°F leaving evaporator temperature
________ MBtuh at ______°F leaving evaporator temperature

Gas energy use at rated conditions: ________ MBtuh

Gas energy use at other conditions and rated RPM:
________MBtuh at ______°F entering condenser temperature
________MBtuh at ______°F entering condenser temperature
________MBtuh at ______°F entering condenser temperature

________MBtuh at ______°F leaving evaporator temperature
________MBtuh at ______°F leaving evaporator temperature
________MBtuh at ______°F leaving evaporator temperature

If performance data are available at reduced speeds or part loads, provide the above data at the reduced speed (specify RPM).

If the unit is designed for engine cooling water heat recovery, what is the available heat recovery at rated and part load conditions:

Rated: _________MBtuh at ______RPM
_________MBtuh at ______RPM
_________MBtuh at ______RPM

Double-effect Absorption Chiller (Commercial)

Rating Conditions
Specify rating standard organization/number (if avail.) _____________
Entering condenser water temperature ______°F
Leaving chilled water (evaporator) temperature _____°F

Full load capacity at rated conditions: ____________ MBtuh
Capacity at other conditions and full load:
________ MBtuh at ______°F entering condenser temperature
________ MBtuh at ______°F entering condenser temperature
________ MBtuh at ______°F entering condenser temperature

________ MBtuh at ______°F leaving evaporator temperature
________ MBtuh at ______°F leaving evaporator temperature
________ MBtuh at ______°F leaving evaporator temperature

Gas energy use at rated conditions: ________ MBtuh
Gas energy use at other conditions and full load:
________MBtuh at ______°F entering condenser temperature
________MBtuh at ______°F entering condenser temperature
________MBtuh at ______°F entering condenser temperature

________MBtuh at ______°F leaving evaporator temperature
________MBtuh at ______°F leaving evaporator temperature
________MBtuh at ______°F leaving evaporator temperature
If performance data are available at part loads, provide the above data at the part load (specify part load fraction).

If the unit is designed for engine cooling water heat recovery, what is the available heat recovery at rated and part load conditions:

Rated: _________MBtuh at ______part load fraction
_________MBtuh at ______part load fraction
_________MBtuh at ______part load fraction

Please indicate whether the unit can also be used to provide hot water for building conditioning (reheat) _________ yes/no. If yes, please provide the heating capacity and efficiency.

Gas Absorption Air Conditioner (Residential)

Rating Conditions
Specify rating standard organization/number (if avail.) _____________
Outdoor air temperature ______°F
Return air temperature _____°F (specify dry bulb or wet bulb)

Full load capacity at rated conditions: ____________ kBtuh
Capacity at other conditions and full load:
________ kBtuh at ______°F outdoor air temperature
________ kBtuh at ______°F outdoor air temperature
________ kBtuh at ______°F outdoor air temperature

________ kBtuh at ______°F return air temperature
________ kBtuh at ______°F return air temperature
________ kBtuh at ______°F return air temperature

Gas energy use at rated conditions: ________ kBtuh
Gas energy use at other conditions and full load:
________kBtuh at ______°F outdoor air temperature
________kBtuh at ______°F outdoor air temperature
________kBtuh at ______°F outdoor air temperature

________kBtuh at ______°F return air temperature
________kBtuh at ______°F return air temperature
________kBtuh at ______°F return air temperature

If performance data are available at part loads, provide the above data at the part load (specify part load fraction).

If the unit is designed for engine cooling water heat recovery, what is the available heat recovery at rated and part load conditions:

Rated: _________kBtuh at ______part load fraction
_________kBtuh at ______part load fraction
_________kBtuh at ______part load fraction

Please indicate whether the unit can also be used to provide hot water for building conditioning (reheat) _________ yes/no. If yes, please provide the heating capacity and efficiency.

Appendix B: ACM Comparison Spreadsheets for the Residential Gas Absorption Air Conditioner

ACM Comparison: Source Energy vs. Time Dependent Valuation Zone 6
Residential Title 24 Compliance Comparison

Project title: 1761sf 2001 Base 2.5 ton
Heating Fuel: Natural Gas

Compliance Comparison Summary				
	Current Method: Source Energy kBtu/sf-yr		**Time Dependent Valuation: kBtu/sf-yr**	
End-Use:	Standard Design Energy Budget	Proposed Design Energy Use	Standard Design Energy Cost Budget	Proposed Design Energy Cost
Space Heating	4.92	4.92	4.98	4.98
Space Cooling	2.36	4.50	7.41	6.19
Water Heating	14.15	14.15	14.84	14.84
Total	21.43	23.57	27.23	26.01
	Complies?	No	Complies?	Yes
	Margin	-10.0%	Margin	4.5%

Fuel Type: Natural Gas

Annual Site Energy Consumption				
	Standard Design		Proposed Design	
End-Use:	Electricity (kWh/sf-yr)	Fuel (kBtu/sf-yr)	Electricity (kWh/sf-yr)	Fuel (kBtu/sf-yr)
Space Heating	0.02	4.73	0.02	4.73
Space Cooling	0.23	0.00	0.08	3.71
Water Heating	0.00	14.15	0.00	14.15
Total	0.25	18.88	0.10	22.58

ACM Comparison: Source Energy vs. Time Dependent Valuation — Zone 10
Residential Title 24 Compliance Comparison

Project title: 1761sf 2001 Base   3 ton
Heating Fuel: Natural Gas

Compliance Comparison Summary				
	Current Method: Source Energy kBtu/sf-yr		Time Dependent Valuation: kBtu/sf-yr	
End-Use:	Standard Design Energy Budget	Proposed Design Energy Use	Standard Design Energy Cost Budget	Proposed Design Energy Cost
Space Heating	9.16	9.16	9.26	9.26
Space Cooling	9.43	19.25	27.24	25.25
Water Heating	14.15	14.15	14.84	14.84
Total	32.74	42.56	51.34	49.35
	Complies?	No	Complies?	Yes
	Margin	-30.0%	Margin	3.9%

Fuel Type: Natural Gas

Annual Site Energy Consumption				
	Standard Design		Proposed Design	
End-Use:	Electricity (kWh/sf-yr)	Fuel (kBtu/sf-yr)	Electricity (kWh/sf-yr)	Fuel (kBtu/sf-yr)
Space Heating	0.03	8.81	0.03	8.81
Space Cooling	0.92	0.00	0.29	16.31
Water Heating	0.00	14.15	0.00	14.15
Total	0.96	22.96	0.32	39.26

ACM Comparison: Source Energy vs. Time Dependent Valuation — Zone 12
Residential Title 24 Compliance Comparison

Project title: 1761sf 2001 Base — 3 ton
Heating Fuel: Natural Gas

Compliance Comparison Summary				
	Current Method: Source Energy kBtu/sf-yr		Time Dependent Valuation: kBtu/sf-yr	
End-Use:	Standard Design Energy Budget	Proposed Design Energy Use	Standard Design Energy Cost Budget	Proposed Design Energy Cost
Space Heating	17.56	17.56	17.58	17.58
Space Cooling	4.93	10.29	15.05	12.08
Water Heating	14.15	14.15	13.41	13.41
Total	36.64	42.00	46.05	43.07
	Complies?	No	Complies?	Yes
	Margin	-14.6%	Margin	6.5%

Fuel Type: Natural Gas

Annual Site Energy Consumption				
	Standard Design		Proposed Design	
End-Use:	Electricity (kWh/sf-yr)	Fuel (kBtu/sf-yr)	Electricity (kWh/sf-yr)	Fuel (kBtu/sf-yr)
Space Heating	0.07	16.88	0.07	16.88
Space Cooling	0.48	0.00	0.15	8.75
Water Heating	0.00	14.15	0.00	14.15
Total	0.55	31.03	0.22	39.78

ACM Comparison: Source Energy vs. Time Dependent Valuation Zone 13
Residential Title 24 Compliance Comparison

Project title: 1761sf 2001 Base 3 ton
Heating Fuel: Natural Gas

Compliance Comparison Summary				
	Current Method: Source Energy kBtu/sf-yr		Time Dependent Valuation: kBtu/sf-yr	
End-Use:	Standard Design Energy Budget	Proposed Design Energy Use	Standard Design Energy Cost Budget	Proposed Design Energy Cost
Space Heating	13.95	13.95	14.12	14.12
Space Cooling	12.67	25.96	29.08	28.15
Water Heating	14.15	14.15	13.41	13.41
Total	40.77	54.06	56.61	55.69
	Complies?	No	Complies?	Yes
	Margin	-32.6%	Margin	1.6%

Fuel Type: Natural Gas

Annual Site Energy Consumption				
	Standard Design		Proposed Design	
End-Use:	Electricity (kWh/sf-yr)	Fuel (kBtu/sf-yr)	Electricity (kWh/sf-yr)	Fuel (kBtu/sf-yr)
Space Heating	0.05	13.42	0.05	13.42
Space Cooling	1.24	0.00	0.38	22.04
Water Heating	0.00	14.15	0.00	14.15
Total	1.29	27.56	0.43	49.61

ACM Comparison: Source Energy vs. Time Dependent Valuation Zone 14
Residential Title 24 Compliance Comparison

Project title: 1761sf 2001 Base 3 ton
Heating Fuel: Natural Gas

Compliance Comparison Summary				
	Current Method: Source Energy kBtu/sf-yr		**Time Dependent Valuation: kBtu/sf-yr**	
End-Use:	Standard Design Energy Budget	Proposed Design Energy Use	Standard Design Energy Cost Budget	Proposed Design Energy Cost
Space Heating	19.71	19.71	20.16	20.16
Space Cooling	12.01	23.98	31.05	31.03
Water Heating	14.15	14.15	14.84	14.84
Total	45.87	57.83	66.04	66.02
	Complies?	No	Complies?	Yes
	Margin	-26.1%	Margin	0.0%

Fuel Type: Natural Gas

Annual Site Energy Consumption				
	Standard Design		Proposed Design	
End-Use:	Electricity (kWh/sf-yr)	Fuel (kBtu/sf-yr)	Electricity (kWh/sf-yr)	Fuel (kBtu/sf-yr)
Space Heating	0.07	18.95	0.07	18.95
Space Cooling	1.17	0.00	0.35	20.37
Water Heating	0.00	14.15	0.00	14.15
Total	1.25	33.10	0.43	53.46

Appendix C: ACM Comparison Spreadsheets for the Non-Residential Gas Engine Driven Chiller

ACM Comparison: Source Energy vs. Time Dependent Valuation Zone 6

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *GasEngineChiller06-Standard*

Output file: GasEngineChiller06-Standard

Proposed Design Building (actual design)

Proposed description: *GasEngineChiller06-Proposed*

Proposed bldg. file: GasEngineChiller06-Proposed

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ06.csv	TDV_kBtu_CTZ06.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,028.7	1,144.3	2,094.3	1,992.7
Complies?	No	Complies?	Yes
	-11.24%		4.85%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
85,871	149.4	73,313	393.6

ACM Comparison: Source Energy vs. Time Dependent Valuation — Zone 10

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *GasEngineChiller10-Standard*

Output file: GasEngineChiller10-Standard

Proposed Design Building (actual design)

Proposed description: *GasEngineChiller10-Proposed*

Proposed bldg. file: GasEngineChiller10-Proposed

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ10.csv	TDV_kBtu_CTZ10.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,131.7	1,185.4	2,306.1	2,041.4
Complies?	No	Complies?	Yes
	-4.74%		11.48%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
95,317	155.8	73,982	427.9

ACM Comparison: Source Energy vs. Time Dependent Valuation Zone 12

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *GasEngineChiller12-Standard*

Output file: GasEngineChiller12-Standard

Proposed Design Building (actual design)

Proposed description: *GasEngineChiller12-Proposed*

Proposed bldg. file: GasEngineChiller12-Proposed

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ12.csv	TDV_kBtu_CTZ12.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,129.0	1,167.4	2,022.7	1,857.8
Complies?	No	Complies?	Yes
	-3.40%		8.15%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
86,540	242.9	69,620	454.5

ACM Comparison: Source Energy vs. Time Dependent Valuation Zone 13

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *GasEngineChiller13-Standard*

Output file: GasEngineChiller13-Standard

Proposed Design Building (actual design)

Proposed description: *GasEngineChiller13-Proposed*

Proposed bldg. file: GasEngineChiller13-Proposed

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ13.csv	TDV_kBtu_CTZ13.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,182.7	1,330.5	2,144.0	2,053.5
Complies?	No	Complies?	Yes
	-12.50%		4.22%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
94,867	211.4	72,669	586.5

ACM Comparison: Source Energy vs. Time Dependent Valuation — Zone 14

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *GasEngineChiller14-Standard*

Output file: GasEngineChiller14-Standard

Proposed Design Building (actual design)

Proposed description: *GasEngineChiller14-Proposed*

Proposed bldg. file: GasEngineChiller14-Proposed

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ14.csv	TDV_kBtu_CTZ14.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,189.8	1,227.8	2,327.4	2,060.8
Complies?	No	Complies?	Yes
	-3.19%		11.45%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
91,706	250.8	71,924	491.3

Appendix D: ACM Comparison Spreadsheets for the Non-Residential Double Effect Absorption Chiller

ACM Comparison: Source Energy vs. Time Dependent Valuation Zone 6

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *std06gd-standard*

Output file: std06gd-standard

Proposed Design Building (actual design)

Proposed description: *dea06deg-Proposed*

Proposed bldg. file: dea06deg-Proposed

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ06.csv	TDV_kBtu_CTZ06.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
995.7	1,244.6	2,016.3	2,089.9
Complies?	No	Complies?	No
	-25.00%		-3.65%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
83,608	139.6	73,072	496.4

ACM Comparison: Source Energy vs. Time Dependent Valuation — Zone 10

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *std10gd-standard*

Output file: std10gd-standard

Proposed Design Building (actual design)

Proposed description: *dea10deg-Proposed*

Proposed bldg. file: dea10deg-Proposed

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ10.csv	TDV_kBtu_CTZ10.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,089.5	1,323.5	2,234.5	2,190.5
Complies?	No	Complies?	Yes
	-21.48%		1.97%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
92,291	144.5	74,840	557.2

ACM Comparison: Source Energy vs. Time Dependent Valuation — Zone 12

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *std12gd-standard*

Output file: std12gd-standard

Proposed Design Building (actual design)

Proposed description: *dea12deg-Proposed*

Proposed bldg. file: dea12deg-Proposed

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ12.csv	TDV_kBtu_CTZ12.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,093.0	1,249.4	1,967.4	1,955.3
Complies?	No	Complies?	Yes
	-14.31%		0.61%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
84,076	232.1	70,993	522.5

ACM Comparison: Source Energy vs. Time Dependent Valuation — Zone 13

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *std13gd-standard*

Output file: std13gd-standard

Proposed Design Building (actual design)

Proposed description: *dea13deg-Proposed*

Proposed bldg. file: dea13deg-Proposed

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ13.csv	TDV_kBtu_CTZ13.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,143.7	1,342.1	2,084.5	2,074.0
Complies?	No	Complies?	Yes
	-17.34%		0.50%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
92,143	200.3	73,867	585.7

ACM Comparison: Source Energy vs. Time Dependent Valuation — Zone 14

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *std14gd-standard*

Output file: std14gd-standard

Proposed Design Building (actual design)

Proposed description: *dea14deg-Proposed*

Proposed bldg. file: dea14deg-Proposed

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ14.csv	TDV_kBtu_CTZ14.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,142.5	1,304.3	2,247.0	2,155.4
Complies?	No	Complies?	Yes
	-14.15%		4.08%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
88,488	236.5	72,877	558.1

Appendix E: ACM Comparison Spreadsheets for the Non-Residential Gas Engine Driven Heat Pump

ACM Comparison: Source Energy vs. Time Dependent Valuation Zone 6

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *std06gd*

Output file: std06gd

Proposed Design Building (actual design)

Proposed description: *ghp06degf*

Proposed bldg. file: ghp06degf

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ06.csv	TDV_kBtu_CTZ06.csv

Compliance Comparison Summary

Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,185.4	1,221.8	2,628.6	2,234.0
Complies?	No	Complies?	Yes
	-3.07%		15.01%

Annual Site Energy Consumption

Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
115,716	0.6	86,510	336.0

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ACM Comparison: Source Energy vs. Time Dependent Valuation — Zone 10

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *std10gd*

Output file: std10gd

Proposed Design Building (actual design)

Proposed description: *ghp10degf*

Proposed bldg. file: ghp10degf

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ10.csv	TDV_kBtu_CTZ10.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,413.2	1,517.6	3,156.2	2,584.9
Complies?	No	Complies?	Yes
	-7.39%		18.10%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
137,869	1.5	93,219	563.1

ACM Comparison: Source Energy vs. Time Dependent Valuation — Zone 12

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *std12gd*

Output file: std12gd

Proposed Design Building (actual design)

Proposed description: *ghp12degf*

Proposed bldg. file: ghp12degf

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ12.csv	TDV_kBtu_CTZ12.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,335.0	1,377.1	2,646.2	2,230.0
Complies?	No	Complies?	Yes
	-3.15%		15.73%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
129,283	11.2	91,295	442.3

ACM Comparison: Source Energy vs. Time Dependent Valuation   Zone 13
Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *std13gd*

Output file: std13gd

Proposed Design Building (actual design)

Proposed description: *ghp13degf*

Proposed bldg. file: ghp13degf

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ13.csv	TDV_kBtu_CTZ13.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,467.3	1,574.9	2,893.3	2,449.1
Complies?	No	Complies?	Yes
	-7.34%		15.35%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
142,492	8.3	93,383	618.7

ACM Comparison: Source Energy vs. Time Dependent Valuation Zone 14

Nonresidential Title 24 Compliance Comparison

Standard Design Building (minimally compliant)

Building Description: *std14gd*

Output file: std14gd

Proposed Design Building (actual design)

Proposed description: *ghp14degf*

Proposed bldg. file: ghp14degf

TDV Climate Values	Currently loaded	Data needed
TDV CTZ file	TDV_kBtu_CTZ14.csv	TDV_kBtu_CTZ14.csv

Compliance Comparison Summary			
Source Energy MMBtu/yr		**Time Dependent Valuation: TDV MMBtu**	
Standard Design Energy Budget MMBtu/yr	Proposed Design Energy Use MMBtu/yr	Standard Design Energy Cost Budget	Proposed Design Energy Cost
1,483.9	1,539.8	3,304.3	2,671.2
Complies?	No	Complies?	Yes
	-3.77%		19.16%

Annual Site Energy Consumption			
Standard Design		Proposed Design	
	Currently loaded		Currently loaded
Electricity (kWh/yr)	Fuel (MMBtu/yr)	Electricity (kWh/yr)	Fuel (MMBtu/yr)
143,654	13.0	98,275	533.5

Appendix F: DOE2 Inputs

GAS ENGINE CHILLERS

TYPE	ENG-CHLR				
SIZE	0.480				
E-I-R	0.00373				Mfg. Value
ENG-CH-COP	1.4				DOE2 Default
ENG-CH-COND-TYPE	TOWER				DOE2 Default
	a	*b*	*c*	*d*	
ENG-CH-COP-FT	1.23624	0.0168923	0	-0.0115235	DOE2 Default
ENG-CH-COP-FTS	1.08815	0.0141064	0	-0.00833923	DOE2 Default
ENG-CH-COP-FPLR1	1.14336	0.0228899	0	0	DOE2 Default
ENG-CH-COP-FPLR2	1.38861	-0.388614	0	0	DOE2 Default
ENG-CH-COP-FPLRS	0.3802	2.3609	0	0	DOE2 Default
ENG-CH-CAP-FT	0.573597	0.0186802	0	-0.00465325	DOE2 Default

DOUBLE-EFFECT GAS-FIRED ABSORPTION CHILLERS

TYPE	ABSORG-CHLR				
SIZE	0.480				
E-I-R	0.00635				Mfg. Value
ABSORG-HIR	1.0				Mfg. Value / DOE2 Default
	a	*b*	*c*	*d*	
ABSORG-HIR-FT	7.82426363	-0.29201	0.0031179	0	Mfg. Value
ABSORG-HIR1-FT1	11.51983798	-0.26178339	0.00162377	0	Mfg. Value
ABSORG-HIR-FPLR	0.13551150	0.61798084	0.24651277	0	DOE2 Default
ABSORG-CAP-FT	1.0	0	0	0	Mfg. Value / DOE2 Default

GAS ENGINE HEAT PUMPS

SYSTEM-TYPE	PSZ				
HEAT-SOURCE	GAS-HEAT-PUMP				
COOLING-EIR	1.657				Mfg. Value
HEATING-EIR	1.382				Mfg. Value
UNIT-AUX-KW	3.4				Mfg. Value
COOL-RPM-LIMITS	3000,1000				DOE2 Default
COOL-CLOSS-MIN	0.8				DOE2 Default
HEAT-RPM-LIMITS	3000,1000				DOE2 Default
HEAT-CLOSS-MIN	0.8				DOE2 Default
	a	*b*	*c*	*d*	
COOL-CAP-FRPM	0.1916220	1.2099284	-0.4015489	0	DOE2 Default
COOL-EIR-FRPM	-0.0059824	1.4111446	-0.4051616	0	DOE2 Default
COOL-CLOSS-FPLR	0.8200000	0.1800000	0	0	DOE2 Default
HEAT-CAP-FRPM	0.3562899	0.5057386	0.1379728	0	DOE2 Default
HEAT-EIR-FRPM	0.2125741	0.6172991	0.1701274	0	DOE2 Default
HEAT-CLOSS-FPLR	0.8200000	0.1800000	0	0	DOE2 Default