Arnold Schwarzenegger
Governor

REALISTIC APPLICATION AND AIR QUALITY IMPLICATIONS OF DG AND CHP IN CALIFORNIA: -Draft- FINAL REPORT

PIER-DRAFT- FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
University of California Irvine
Advance Power and Energy Program

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South Coast Air Quality Management District	Howard Lange	Local Agency
California Air Resources Board	Dave Mehl	State Agency
Sempra Energy Utilities	Henry Mak	Utility
Southern California Edison	Rudy Perez, Bob Levine	Utility
LPA	Dan Heinfeld	Architect/End User
CTG	Jim Meacham	Architect/End User
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Fuel Cell Energy	Jeff Cox	Technology OEM
Ingersoll Rand	~~George Wiltsee,~~Andrew Freeman	Technology OEM
Solar Turbines	Mark Hughes	Technology OEM
Cummins Power Generation	Eric Wong	Technology OEM
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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

- PIER funding efforts are focused on the following RD&D program areas:
- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation
- *Realistic Application and Air Quality Implications of DG and CHP in California; Phase 1 Interim Report* is the interim report for the Realistic application and Air Quality Implications of DG and CHP in California project (contract number 500-02-004, work authorization number [CIEE MR-026 conducted by the University of California Irvine Advanced Power and Energy Program. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

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Abstract

The value of and the opportunity for distributed generation (DG) as well as the recovery of waste heat for other beneficial purpose is ever increasing. Pressure on the existing electric distribution grid to meet increasing demands, pressure on reductions in emissions of both criteria pollutants and greenhouse gases, and pressures for improved on site power reliability and reduced energy expenditures all support the concept of local and diffused power generation systems located at the point of application. To better understand the opportunities and the subsequent impact of wide spread application of DG with waste heat recovery (referred to as combined cooling, heating, and power DG/CCHP), it is vital to (1) identify facilities that would most likely benefit from the application, (2) understand and document the typical energy profiles and (3) assess the effects, if any, of localized emissions from the DG/CCHP on the immediate surroundings.

This program addresses all of these crucial points:

- An assessment of a wide variety of building/business types was made and six sectors identified (hospitals/healthcare, jails/prisons, colleges/universities, large commercial office, food and grocery, and hotel) as high energy intensity facilities that would likely have energy profiles and needs that would benefit from DG/CCHP. Moreover, the existing and projected energy demands are such that the application of DG/CCHP could have a significant impact
- Long term monitoring of the energy profiles of the facility, both the energy that crosses the boundary of the facility (i.e. grid electric and natural gas) and the internal use of the energy for demands that could be met with waste heat recovery such as space heating and cooling was completed. The program documents the energy profiles for approximately 50 buildings over the period of nominally 12 months at 15 minute time interval. This data is assembled in a SQL data base for subsequent analysis and evaluation.
- The effects of DG/CCHP on both the near field adjacent to the system and the South Coast Air Basin (SoCAB) were analyzed through computer modeling. The results suggest minimal effect on the near field as a result of exhaust plume dispersion for several cases. On a basin wide level, the impact of extensive deployment of DG/CCHP in the sectors can result in the elimination of one or more of the large central power plants in the SoCAB. The effect on the overall air quality as measured by ozone and PM2.5 is zero to slight improvement relative to the pre-deployment situation. However the implementation of DG/CCHP does eliminate high concentration zones that can be attributed to the elimination of the Central power plants.

Executive Summary

The value of and the opportunity for distributed generation (DG) as well as the recovery of waste heat for other beneficial purpose is ever increasing. Pressure on the existing electric distribution grid to meet increasing demands, pressure on reductions in emissions of both criteria pollutants and greenhouse gases, and pressures for improved on site power reliability and reduced energy expenditures all support the concept of local and diffused power generation systems located at the point of application. The use of small and mid-sized DG CHP in the state is expected to grow significantly between now and 2020 due to ongoing policy and legislation directed at enhancing the stability of California's electricity supply and meeting global warming goals. However, the use of DG CHP in urban areas can potentially increase exposure to air pollutants. The available data of averaged profiles and predicted building load demands is not adequate for understanding the performance of these units. The present program addresses this insufficiency in order to (1) establish the validity of currently assumed load profiles, and (2) delineate actual building load profiles and thereby provide the data needed to accurately predict the impact of DG CHP on air quality.

In order to accurately determine the air quality impacts of distributed generation (DG) sited in possible California locations, an estimate of the emission signature of the "as deployed" DG device is needed. For example, DG can be deployed in a manner that recovers the waste heat and uses it for heating and/or cooling, which is referred to as combined heat and power (CHP). The mass of emissions produced by a DG/CHP system is dependent upon how it is operated and its overall efficiency. How the DG/CHP system operates is strongly tied to the application it is being used in, the electric and natural gas utility rates, and the building demand profile. As a result, it is necessary to understand how a given DG/CHP system is operated for various applications in order to establish a representative emissions signature.

For CHP to be cost effective, the heat waste must be recovered most if not all of the time. For most applications that consider CHP, the monthly or yearly quantities of electricity and heat use indicate that a CHP system should work efficiently. However, this is often not the case due to the miss-match between the moment-by-moment electric and heat demand. As a result, CHP systems need, in principle, to match the timing of the needed heat and electricity on a real-time basis, since storing either heat or electricity even on a short term basis is not economically practical. In addition, the temperature of waste heat from the DG generator must meet minimum quality levels demanded by the load requirements. If either of the timing or quality does not match, then only a small fraction of the waste heat can be used, greatly decreasing the overall efficiency of the CHP unit and increasing overall emissions from the unit. As a result, time resolved information regarding building load (electrical and thermal) demands and how DG/CHP systems are deployed to optimally meet this demand is needed in order to accurately determine the emissions profile of the system.

To better understand the opportunities and the subsequent impact of wide spread application of DG with waste heat recovery (referred to as combined cooling, heating, and power DG/CCHP), it is vital to (1) identify facilities that would most likely benefit from the application, (2) understand and document the typical energy profiles and (3) assess the effects, if any, of localized emissions from the DG/CCHP on the immediate surroundings

The goals of this program address the three hurdles defined previously. Specifically:

1. identify facilities that would most likely benefit from the application,
2. understand and document the typical energy profiles and
3. assess the effects, if any, of localized emissions from the DG/CCHP on the immediate surroundings.

The facilities identified for study and most likely to benefit from deployment as well as impact the grid and environment are: hospital, hotels, jails/prison, colleges/universities, large commercial office buildings, and food/grocery. In the process of engaging facilities, over 200 sites were approached to participate in the program through a combination of (i) instrumented energy measurements made by UCI and program supplied equipment, (ii) recovery and download of existing facility energy management system (EMS) data, and (iii) access to utility records for the facility for grid electric and natural gas consumption. The goal of the program was to engage approximately 100 to 120 facilities spread evenly across the six sectors identified. In the end, there were a total 48 facilities that were engaged in the program with the following distribution:

- Hospital/Health Care Facilities: 6
- Hotel: 4
- Jails/Prisons: 9
- Colleges/Universities: 9
- Large Commercial Office: 18
- Food/Grocery: 12 (eleven grocery stores + one warehouse distribution center)

The lack of engagement of both hospitals and hotels was unexpected. For hotels, the lack of participation is likely due to the perception on the part of hoteliers that competitors could access competing facility energy data; operating information is generally considered competition sensitive. For hospitals, the lack of participation is likely due to a desire to not have operational history available for scrutiny lest it lead to some government oversight (e.g. OSHPD) review and intervention. Both of these conclusions are strictly the perception of the investigators and not expressed or confirmed by facilities in the sectors.

The goal of the energy monitoring effort is to document the energy profile of the represented facilities including:

- energy crossing the border of the facility (i.e. grid electricity and natural gas),
- any on site power generation whether fuel based or renewable, and
- the energy required for heating and cooling needs, whether domestic hot water, HVAC,
- the energy required for process heating and cooling, that could be met with waste heat recovery strategies.

Furthermore, the goal was to obtain this energy data for a period of at least 12 months (to represent seasonal variations) at intervals of 15 minutes. For the majority of the sites, this goal was readily accomplished. The structured query language (SQL) data base has over 5 million lines.

The evaluation of the energy profiles and the applicability of DG/CHP to the sites are still in process. Initial impressions are that all sectors can make use of the DG/CHP in an effective manner to increase overall facility efficiency, reduce criteria and greenhouse gas emissions, and likely provide prima fascia economic benefits. However, the actual implementation and savings may be different than theory. One aspect of this program was to monitor facilities that currently had operating DG/CHP systems installed. Of the 48 participating facilities, four had operational DG/CHP systems. Three installations were microturbines with waste heat recovery while the fourth was a molten carbonate high temperature fuel cell.

The results of the real world DG system monitoring reflect seasonal variations in waste heat captured reflective of the ambient temperature variations. That is, waste heat recovery for hot water . Reduction in the hot water demands in the summer/warm months is quite evident as compared to the recovery in winter/cool months. Conversely, one site monitored utilized waste heat to drive a 100 ton absorption chiller for cooling demands. Hence, higher overall efficiencies were noted in the summer as compared to the winter. Microturbine generators comprised three of the monitored installations and demonstrated nominal annual overall thermal efficiencies of approximately 55%. The fourth molten carbonate fuel cell installation exhibited nominal annual overall thermal efficiencies of approx 70%, partly owing to the combination of sensible and latent heat recovery.

The impact of DG/CHP on surrounding population was also investigated. Computational fluid dynamic modeling of exhaust plume dispersion from a DG system (specifically a microturbine) indicates that the plume is diluted to levels at or below the Ambient Air Quality Standards within 100 ft of the exit plane. To be conservative, a region of potential influence was defined as 100 meters surrounding the facility. Focusing on the Southern California Air Basin region representing a population of approximately 17.9 million people, the permanent resident population that is within the region of influence is approximately 3.2% and night and 7.2% during the day. However, the estimation of the region of influence considers 360-degrees around each facility and does not consider subsets of population that would be affected by other circumstances such as prevailing winds.

This research supports California's goal to encourage the development of environmentally-sound combined heat and power resources and distributed generation projects by providing a better understanding of the efficiencies and emissions of various applications of DG CHP systems to aid in optimal DG CHP system design and placement. This research will help policy makers better understand the value of CHP, and will help to better determine the amount of emission credits to allocate CHP units. For example, this research has shown that the food and grocery industry which includes grocery stores and convenience stores (e.g. 7- Eleven), which currently has a very low use of DG-CHP, would be an excellent candidate for use of this system while reaping one of the highest efficiencies and smallest emissions footprint. In California as a whole, there are more than 6,800 food/convenience stores with revenues greater than $1,000,000 annually and representing approximately 3,000 GW-hr of energy consumption[i]. The results of this program indicate that a DG/CHP system typically meet > 90% of the all of the energy demands at a food/convenience store through both the on-site electric power generation and the displacement of more than 50% of the refrigeration needs through the application of thermally activated cooling driven by waste heat. Further, the overall thermal efficiency of such a system would be > 75% and result in a net reduction in natural gas consumption of approximately 20% over a full grid feed for the electric power. The savings of 6 million MMbtu of natural gas would result in a reduction of 320,000 MT of carbon dioxide emissions annually. Further, the engineering needs for the effective application of DG in the food and convenience market sector have been better defined in terms of improvements in thermally activated cooling to lower temperature applications and the development and deployment of secondary fluid refrigeration systems at food and convenience stores. Technology advances in this arena which will help the DG and associated CHP industry to provide better products to meet California's electricity generation goals.

[i] 50 kW average power demand annually

1.0 Introduction

In order to accurately determine the air quality impacts of distributed generation (DG) sited in possible California locations, an estimate of the emission signature of the "as deployed" DG device is needed. For example, DG can be deployed in a manner that recovers the waste heat and uses it for heating and/or cooling, which is referred to as combined heat and power (CHP). The mass of emissions produced by a DG/CHP system is dependent upon how it is operated and its overall efficiency. How the DG/CHP system operates is strongly tied to the application it is being used in, the electric and natural gas utility rates, and the building demand profile. As a result, it is necessary to understand how a given DG/CHP system is operated for various applications in order to establish a representative emissions signature.

For CHP to be cost effective, the heat waste must be recovered most if not all of the time. For most applications that consider CHP, the monthly or yearly quantities of electricity and heat use indicate that a CHP system should work efficiently. However, this is often not the case due to the miss-match between the moment-by-moment electric and heat demand. As a result, CHP systems need, in principle, to match the timing of the needed heat and electricity on a real-time basis, since storing either heat or electricity even on a short term basis is not economically practical. In addition, the temperature of waste heat from the DG generator must meet minimum quality levels demanded by the load requirements. If either of the timing or quality does not match, then only a small fraction of the waste heat can be used, greatly decreasing the overall efficiency of the CHP unit and increasing overall emissions from the unit. As a result, time resolved information regarding building load (electrical and thermal) demands and how DG/CHP systems are deployed to optimally meet this demand is needed in order to accurately determine the emissions profile of the system.

1.1. Scientific and Technological Baseline

The temperature and timing demand for heat energy compared to simultaneous electricity use is not established for a significant sample of commercial facilities located in California urban areas. Some hourly electricity use for larger facilities such as hospitals is available, but little highly resolved load profile data exist at businesses and facilities with electrical demands of 1 MW or less. Such building load information is commonly reported in annual or monthly averages.[2,3,4,5,6] Moreover, existing CHP applications of 1 MW and less are not regulated and relevant operational data are often not retained or reported. As a result, a need exists for

[2] National Account Sector Energy Profiles 2003 EEA
[3] Market Assessment of Combined Heat and Power Market in California, ONSITE SYCOM Energy Corporation, December 22, 1999
[4] The Market and Technical Potential for Combined Heat and Power in the Industrial Sector, ONSITE SYCOM Energy Corporation, January 2000
[5] The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector, ONSITE SYCOM Energy Corporation, January 2000
[6] The Combined Heat and Power Database, EEA, 2005 http://www.eea-inc.com/testchp/index.html

detailed hourly (or even higher rate) information on typical application electricity and thermal requirements that can then be used in analysis of emissions output of potential DG/CHP systems that might be deployed to meet those requirements. This information can be used to more accurately assess the air quality impact of DG/CHP system.

In addition to the previously cited efforts,[2-6] other tabulated information is available for building energy consumption. Some information regarding building energy consumption is available through the Energy Information Agency. An example is the Commercial Building Energy Consumption Survey from 1995 which summarizes information for 27 different general building types and provides a wealth of information as a function of various parameters such as year build, HVAC technology type, etc. However, this information is all time averaged and generally tabulated on an annual basis.

The U.S. Department of Energy has available annual Building Energy Databooks which again provide detailed tabulated data on energy consumption for different building types. Again, however, this information is based on annual consumption.

On the other hand, modeling efforts have evolved to the point where hourly demand data can be utilized. Examples of simulation software that can incorporate hourly building demand information includes DER-CAM[7] (Distributed Energy Resource Customer Adoption Model) and eQUEST.[8] EQUEST incorporates the DOE-2 building simulation software, which has libraries of simulated building demand information. To support some of these efforts, data have been obtained which is similar in nature to that proposed under the current effort. However, it is very sparse in nature, not systematic across many building types, and does not have the time resolution desired. Any of these existing data, to the extent possible, will be included in the database developed as part of the proposed effort so they can be included in the overall air quality impact assessment.

In summary, very limited data are available with which to carry out more accurate predictions of the air quality impacts of DG/CHP systems in California. A systematic collection of this information is required with the time resolution necessary to (1) establish advanced DG deployment scenarios (e.g., based on real time price signals or "emission based deployment" strategies) and (2) facilitate the subsequent integration of this information into an interactive database that can be used in conjunction with air quality impact models to provide air quality impact estimates.

1.2. Relevant Work at APEP

The Advanced Power and Energy Program (APEP) has considerable experience in monitoring the energy consumption of buildings consistent with the tasks outlined in the solicitation. This analysis has been conducted to support models of building integration of distributed generation. As mentioned above, the deployment and optimal equipment configuration for each application will be dependent upon a number of factors, perhaps most critical of which is

[7] Siddiqui, A., Firestone, R., Ghosh, S., Stadler, M., Edwards, J., and Marnay, C. (2003). Distributed Energy Resource Customer Adoption Modeling with Combined Heat and Power Applications.
[8] Quick Energy Simulation Tool (available at http://www.doe2.com/equest/) accessed 10 January 2006.

the actual building energy profile. By way of example, Figure 1 and Figure 2 illustrate measurements obtained by APEP for a commercial office building located in Southern California for one day[9]. The results in Figure 1 show the relative contribution of air conditioning and total energy demand. The results allow an actual DG dispatch scenario to be developed for this type of building for a period in November 2004. Figure 2 shows demand based on 3 second and 5 minute averages. These results show that considerable detail is observed in the data. As part of the first task in the proposed work, input will be sought relative to the necessary resolution. Equipment available for measurement of the information needed is capable of acquiring data at very high resolution.

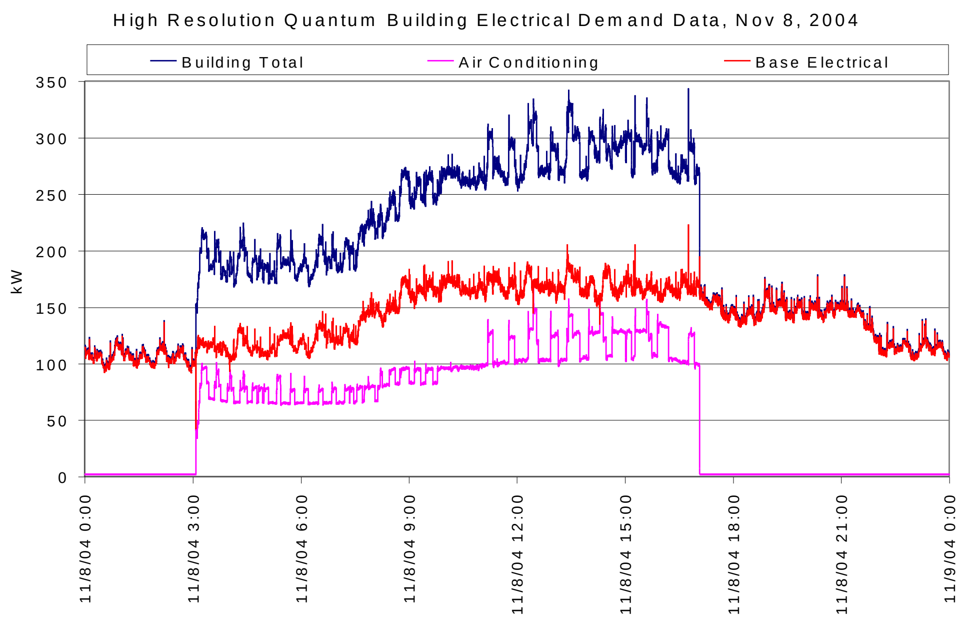

Figure 1. Typical high resolution demand data used for analyses.

[9] Meacham, J: Masters thesis

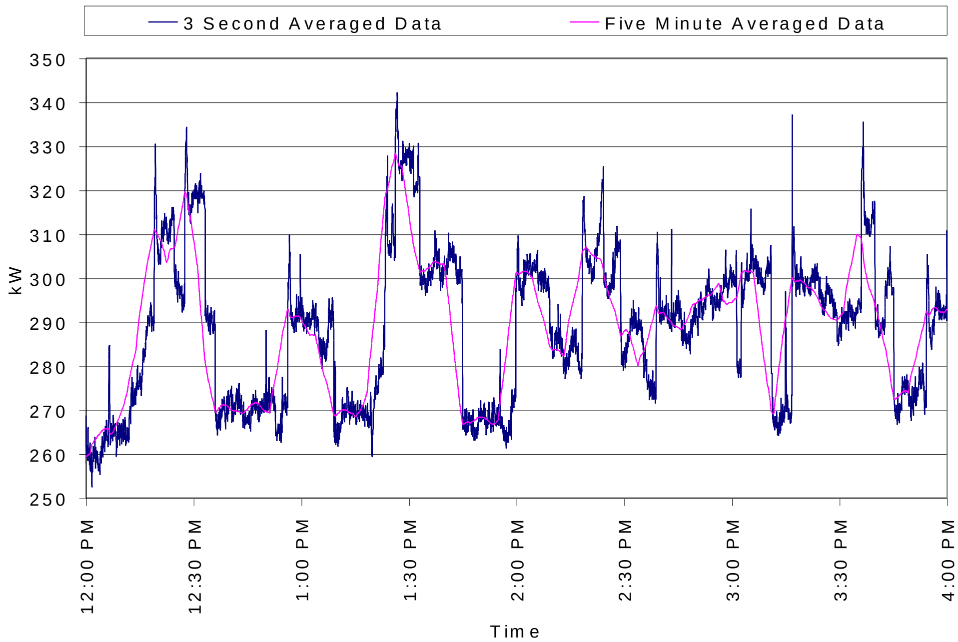

Figure 2. Comparison of 3-second and 5-minute averaged demand data.

Examples of analyses and results from this monitoring program have been recently published.[10],[11] In the proposed activity, remote monitoring may be of interest and will be used as needed. In the proposed effort, monitoring of the DG device utilization *and* the building demand profile will occur and information from devices monitoring building demands will be collected. This existing infrastructure can be incorporated into the current program to provide users access to the data collected in a searchable, interactive manner.

In terms of air quality impact assessment, APEP has been conducting studies for the past four years under funding from the California Energy Commission and which has been reported at various venues.[12,13] This experience relates to the current project because the inputs needed for the air quality impact simulations have been well established for the prior projects. As a result, the development of databases and the format of the information needed for using the results efficiently for calculations are already in hand at APEP.

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[10] EXPERIENCES WITH MICROTURBINE GENERATOR SYSTEMS INSTALLED IN THE SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT (2003). Paper GT-2003-38777, presented at IGTI Turbo EXPO 2003, Atlanta GA, June (V.G. McDonell, R.L. Hack, S.W. Lee, J.L. Mauzey, J.S. Wojciechowski, and G.S. Samuelsen).

[11] MONITORING MICROTURBINE GENERATORS INSTALLED IN THE SOUTH COAST AIR BASIN (2005). Paper GT2005-68520, ASME Turbo EXPO 2005, Reno, NV, June (M. Medrano, R.L. Hack, S.W. Lee, V.G. McDonell, S.Samuelsen, M. Kay, and H. Lange).

[12] Medrano, M., Brouwer, J., Samuelsen, G.S., Carreras, M., and Dabdub, D. 2003, "Air Quality Impacts of Distributed Generation, Final DG Scenario Development Report," California Energy Commission Contract 500-00-033.

[13] Carreras, M., Brouwer, J., Medrano, M., Rodriquez, M., Samuelsen, G.S., and Dabdub, D., 2004 "Urban air quality impacts of distributed generation" Paper GT2004-54252, ASME TurboExpo 2004, Vienna, June.

APEP has, in addition to acquiring data needed for the proposed work, also developed the infrastructure and protocol for logging, reducing, and tabulating the data obtained which will be a critical element of the proposed effort. In particular, the development of an SQL server based database allows a query based approach to extract information of interest. This can be used to post data on the web with an efficient, user-interactive presentation of results. This work was funded by the South Coast Air Quality Management District (AQMD) and the U.S. Department of Defense (DoD) under projects involved with remote monitoring and presentation of data from installed and operating distributed generation systems, many of which are utilizing a variety of waste heat recovery.

1.3. Barriers and Issues

The reason that the proposed data are not available today is two fold. First, the acquisition of the necessary time-resolved data requires specialized equipment, which is not typically available at a site of interest. While utility bills can provide an idea of the monthly or annual usage, tracking this on a hour by hour or minute by minute basis requires specialized equipment. Second, compilation of the data into a user friendly database requires experience, specialized equipment, and considerable effort to develop an interface.

In summary, air quality impacts of DG have evolved to the point where reliance upon predicted building load demands is no longer sufficient. The present program addresses this insufficiency in order to (1) establish the validity of currently assumed load profiles, and (2) delineate actual building load profiles and thereby provide the data needed to accurately predict the impact of DG on air quality.

1.4. Relationship to PIER Goals

This Agreement addresses the Energy-Related Environmental Research goal of resolving impacts from electricity generation, transmission, and use by providing an improved estimate of the air quality impact of distributed generation. It also addresses the goal of providing basic scientific information and tools needed to understand the environmental implications of technology and fuel types to inform the R&D choices undertaken elsewhere in the PIER Program.

1.4.1. Goals of the Agreement

The goals of this Agreement are:

- To publish an interactive on-line database of hourly (or higher resolution) profiles of power, heating, and cooling demand for common small industries
- To produce a final report that summarizes the value of DG/CHP systems in terms of emissions impacts, illustrates the engineering needs for effective application of DG/CHP, and recommends applications that most effectively benefit from DG/CHP installation in terms of overall efficiency and air quality impacts.

1.4.2. Objectives of the Agreement

The objectives of this Agreement are to:

- Identify 5 facility types that show high potential for successful DG/CHP applications in southern California
- Identify 20 facilities of each type to participate in the study, including approximately 10 that already have DG/CHP installed
- Install and measure the real time electrical, heating, and cooling demand for the 100 facilities identified for 1 month within each season of the year (i.e., total of 4 months of data for each facility).
- At the sites with existing DG/CHP, establish monitoring needed to document (1) the system overall efficiency and (2) details regarding the time over which the system is deployed.
- Collect additional information regarding each site including type and location of the facility, the type of equipment used, and utility rate information
- For the sites with DG/CHP installed, characterize the utilization of the DG/CHP system during the time which the building load is monitored.
- Develop an SQL database to retain and archive the data collected
- Assimilate the data into the SQL database
- Use the data to determine the relative time during which CHP can be used at the facility
- Determine the overall efficiency for DG/CHP systems that are already installed
- Determine the mass of pollutants emitted at each site as a function of time
- Produce a report with an analysis of the relative exposure of the DG/CHP system for each facility type including the influence of population proximity.
- Produce a summary of relative benefits for each facility type including economics as well as air quality impacts.

As a result of this research, an hourly profile of the power, heat and cooling use of some common small industries will be obtained and made available to the public. An analysis of the benefits of installing and using CHP systems will be conducted on several facility types that have been identified as successful candidates for DG/CHP use. This research will help policy makers better understand the value of CHP, and will help to better determine the amount of credits to allocate CHP units. Further, the engineering needs for the effective application of DG will be better defined, which will help the DG and associated CHP industry to provide better products to meet California's electricity generation goals.

2.0 Facility Identification

Intuitively, facilities that would most benefit from the application of DG/CHP would be those that have high thermal loads or air conditioning loads that also have needs for 24/7 operation. However, a more supportable methodology for evaluation of the sites was necessary. The application of DG/CHP and its potential impacts have been evaluated on several occasions with detailed reports defining "global" system requirements (such as system power needs, total potential installed capacity) across a variety of facility types (SIC code delineated facilities) have been published. With the compiled system application information, a review of actual deployment, and through a process of weighting the facility attributes, this effort provided a quantitative ranking of sectors. This was reviewed with the advisory committee and a final set of "sectors" identified for the program.

The initial goal for the program was to define 5 sectors with approximately 20 facilities in each sector. At the end of the Phase 1 effort, 6 sectors were identified and data from approximately 50 sites compiled.

2.1. Sector Identification and Evaluation

2.1.1. Energy Information Resources / Sector Identification

Data from a CEC report by EEA[14] was used to screen and rank sectors based upon the current and projected cumulative energy production needs, the current and projected co-generation needs, weighting based upon the size of the on site energy needs (Figure 3). This information was combined with the data bases documenting the self generation application records for California[15], and the California Commercial End Use Survey[16] (Figure 4) as well as input from the industrial advisory panel to glean a top 10+ list of possible sectors, all demonstrating energy intensity and CHP opportunity (Figure 5), and the perceived acceptance and cooperation of the sectors were used to rank the top ten sectors.

2.1.2. Sector Evaluation

To quantify the suitability of the subset of sectors, sector characteristics were evaluated based upon weighting criteria. The weighting factors (Figure 6) were developed by UCI and presented to the Advisory panel for discussion. The weighting criteria are presented in Figure 7 based upon the consensus of the panel. Applying the weighting criteria to the EEA and CEUS data resulted in the ranking of sectors presented in Figure 8. Note that separate lists are presented for cases with and without consideration of the load factor for the facility. The load

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[14] Assessment of California CHP Market and Policy Options for Increased Penetration, April 2005; prepared for the California Energy Commission by the Electric Power Research Institute (EPRI) and Energy and Environmental Associates (EEA); Report Number CEC-500-2005-060-D

[15] California Self Generation Incentive Program Data Base: www.sce.com/RebatesandSavings/SelfGenerationIncentiveProgram

[16] California Commercial End Use Survey, March 2006; prepared for the California Energy Commission by Itron Inc, Report NumberCEC-400-2006-005

factor is defined as the fraction of the time that the facility would be expected to utilize the energy as well as an estimate of when the energy needs are high. For example, hospitals would be considered to have a load factor near 1 with facility needs, although likely reduced at night, around the clock. Conversely, retail stores and commercial office buildings would have virtually no load after closing time. In fact, commercial office buildings were assigned a load factor of only 0.33 representing on average 11 hours of operating time, Mon – Fri, per week.

Technical Market Potential for Traditional CHP in Existing Facilities

SICs	Application	50-500 kW Sites	50-500 kW MW	500-1 MW Sites	500-1 MW (MW)	1-5 MW Sites	1-5 MW (MW)	5-20 MW Sites
20	Food	1,183	177.5	279	209.3	206	515.0	13
22	Textiles	369	41.5	49	27.6	15	28.1	0
24	Lumber and Wood	543	16.3	82	12.3	30	15.0	2
25	Furniture	567	25.5	58	13.1	32	24.0	0
26	Paper	255	38.3	163	122.3	123	307.5	5
28	Chemicals	675	101.3	226	169.5	224	560.0	4
29	Petroleum Refining	189	28.4	31	23.3	12	30.0	3
30	Rubber/Misc Plastics	645	29.0	409	92.0	196	147.0	0
33	Primary Metals	321	12.0	105	19.7	119	74.4	1
34	Fabricated Metals	1,710	77.0	285	64.1	114	85.5	0
35	Machinery/Computer Equip	2,429	91.1	343	64.3	162	101.3	0
37	Trasportation Equip.	548	41.1	217	81.4	150	187.5	5
38	Instruments	892	66.9	295	110.6	176	220.0	1
39	Misc Manufacturing	622	23.3	48	9.0	27	16.9	1
6512	Commercial Buildings*	5,991	898.7	2,230	669.0	723	903.8	0
6513	Apartments	1,899	113.9	686	102.9	104	83.2	0
7542	Carwashes*	496	74.4	3	2.3	0	0.0	0
8412	Museums*	195	29.3	24	18.0	0	0.0	0
4222	Warehouses	129	19.4	152	114.0	8	20.0	0
4941	Water Treatment/Sanitary	267	40.1	141	105.8	110	275.0	1
7011	Hotels	3,370	379.1	661	371.8	270	506.3	12
7211	Laundries*	225	33.8	10	7.5	0	0.0	0
7991	Health Clubs*	648	97.2	130	97.5	2	5.0	0
7992	Golf/Country Clubs*	537	80.6	66	49.5	0	0.0	0
8051	Nursing Homes	1,056	158.4	376	282.0	16	40.0	0
8062	Hospitals	222	33.3	184	138.0	302	755.0	3
8211	Schools	3,016	226.2	650	243.8	65	81.3	7
8221	Colleges/Universities	268	40.2	231	173.3	116	290.0	71
9223	Prisons	67	10.1	77	57.8	49	122.5	15
	Total	**29,334**	**3,003.5**	**8,211**	**3,451.3**	**3,351**	**5,394.1**	**144**

Figure 3: Technical Market Potential for Traditional CHP in Existing Facilities[17]

Building Type	Floor Stock (kft^2)	Annual Energy Intensities: Electricity (kWh/ft^2)	Annual Energy Intensities: Natural Gas ($therms/ft^2$)	Annual Energy Intensities: Natural Gas ($kBtu/ft^2$)	Total Annual Usage: Electricity (GWh)	Total Annual Usage: Natural Gas (Mtherms)
All Commercial	4,920,114	13.63	0.26	25.99	67077	1278.60
Small Office (<30k ft^2)	361,584	13.10	0.11	10.54	4738	38.10
Large Office (>=30k ft^2)	660,429	17.70	0.22	21.93	11691	144.80
Restaurant	148,892	40.20	2.10	209.98	5986	312.60
Retail	702,053	14.06	0.05	4.62	9871	32.50
Food Store	144,209	40.99	0.28	27.60	5911	39.80
Refrigerated Warehouse	95,540	20.02	0.06	5.60	1913	5.30
Unrefrigerated Warehouse	554,166	4.45	0.03	3.07	2467	17.00
School	445,106	7.46	0.16	15.97	3322	71.10
College	205,942	12.26	0.34	34.24	2524	70.50
Health	232,606	19.61	0.76	75.53	4561	175.70
Lodging	270,044	12.13	0.42	42.40	3275	114.50
Miscellaneous	1,099,544	9.84	0.23	23.34	10817	256.60
All Offices	1,022,012	16.08	0.18	17.90	16430	182.90
All Warehouses	649,706	6.74	0.03	3.44	4380	22.40

Figure 4: Technical Market Potential for Traditional CHP in Existing Facilities[18]

[17] PIER-CEC/EPRI/EEA Report; April 2005; CEC-500-2005-060-D
[18] CEUS Data Base

	MW Potential			
Top 10 Sectors	Total	<1 MW	< 5MW	Not
Commercial Buildings	2471	1568	2471	Low Load Factor may limit
Colleges/Universities	1991	21	503	Medium to large facilities:difficult to
Hotels	1370	75	1257	
Food	1067	387	902	
Hospitals	964	172	926	Difficult to implement DG/CHP; OSHPD hurdle.
Chemicals	858	271	831	Need to look for smaller applications.
Schools	595	470	551	
Paper	533	160.6	468	
Nursing Homes	480	440	480	
Water Treatment/Sanitary	433	146	421	Opportunity Fuels
Transportation Equip	431	122.5	310	
Prison	378	68	190.5	
Health Clubs	200	195	200	

Future Market (2005-2020)

	MW Potential			
Top 10 Sectors	Total	< 1MW	< 5MW	Note
Commercial Buildings	1352	857	1352	Low Load Factor may limit payback
Chemicals	927	292	897	Need to look for smallish applications;
Colleges/Universities	732	114	269	Medium to large facilities:difficult to instrument.
Transportation Equipment	466	131	334	Do not know what is included in this
Hospitals	325	60.5	325	Difficult to implement DG/CHP; OSHPD huge hurdle.
Schools	320	251	295	
Prisons	287	52.1	150	
Hotels	218	119.3	200	
Health Clubs	214	209	214	
Water Treatment/Sanitary	174	61.3	174	Opportunity Fuels

Figure 5: Top 10 Sectors for Evaluation based upon Current and Future DG/CHP potential

<u>Sector Analysis</u>

- **Current Market Potential - weighting based upon installed MW and CHP application**
- **Future Market Potential – weighting based upon installed MW potential CHP application**
- **Utilization of Opportunity Fuels – added weighting if renewable fuels can be incorporated**
- **Site Cooperation/Regulatory Hindrances – weighting to consider:**
    - **Are sites supportive of DG/CHP in general?**
    - **Are their government or other regulatory agencies that are reluctant to support DG/CHP or have substantial hurdles that can complicate and extend the process to the point of being undesirable**
        - **OSHPD for hospitals and health care**
        - **State Architect for public institutions**
- **CHP Integration Potential/Value – weighting based upon potential for efficiency and economic benefits to end user.**

Figure 6: Criteria for Evaluation of Sectors

		Weighting	Criteria/Value	[units]	Score
1	Market Potential (EEA Report)				
	Electric + Heat				
	Current				
	Cum. Capacity less than 1 MW/installation	10		[MW]	
	Cum. Capacity less than 5 MW/installation	10		[MW]	
	Future				
	Cum. Capacity less than 1 MW/installation	13		[MW]	
	Cum. Capacity less than 5 MW/installation	13		[MW]	
	Electric + Heat + Cooling				
	Current				
	Cum. Capacity less than 1 MW/installation	17		[MW]	
	Cum. Capacity less than 5 MW/installation	17		[MW]	
	Future				
	Cum. Capacity less than 1 MW/installation	20		[MW]	
	Cum. Capacity less than 5 MW/installation	20		[MW]	
2	Utilization of Opportunity/Renewable Fuels (additive benefit with above)	20		[MW]	
3	Estimated Annual Load Factor	1		fraction of year	
4	Site Cooperation/Regulatory Hinderances (1-10) (e.g. agencies that regulate deployment such as OSHA, OSHPD)	10			

Figure 7: Weighting Factors for Evaluation Criteria

- **With Annual Load Factor**
  - **Hotel**
  - **Food/Restaurant**
  - **Commercial Building**
  - **Hospital**
  - **Chemical**
  - **Nursing Home**
  - **Retail**
  - **Water/Sanitary**
  - **Prisons**
  - **Colleges/Univ.**

Without Annual Load Factor

- **Commercial Building**
- **Food/Restaurant**
- **Hotel**
- **Hospital**
- **Chemical**
- **Retail**
- **Nursing Home**
- **Schools**
- **Colleges/Univ.**
- **Health Clubs**

Figure 8: Ranking of Sectors with and without annual load factor consideration.

From the list presented in Figure 8, further sector considerations such as anticipated cooperation and acceptance of the technology, generic nature of the sector definition, nominal size of the installation as compared to the definition of distributed generation were considered. For example, hospitals and healthcare are considered to be prime candidates for DG/CHP. However, the state agency that regulates hospitals (OSHPD) has generally displayed an aversion to the application DG/CHP technology which would negatively impact the perceived success of penetrating this market with DG/CHP. Additionally, while the Industrial / Chemical application opportunities would seem to be a prime candidate, the advisory panel deemed both to be too broad a categorization, making it difficult to identify a "typical" industrial or chemical process that could be monitored for evaluation. Rather, the industrial/chemical sector could form the basis for a study unto itself, with multiple processes evaluated.

The results presented in Figure 8 reveal many sectors that would be intuitive (hotels, hospitals) while identifying others that would not have been quite so obvious (food/restaurant). The advisory committee was unsure how to interpret the restaurant subsector's standing; further it was difficult for the committee to fully understand how to monitor such a facility. Hence, the "food" aspect was retained in the form of grocery store and food distribution warehouses but "restaurants" were eliminated as a sector. In general, facilities that house and cater to people were seen as more applicable to the DG/CHP strategy owing to the care and comfort issues. Commercial office buildings and colleges and universities are a bit outside of the rule owing to their non 24/7 operation (most have reduced or no population outside of operating hours). The food sector is a definite outlier in the corollary but the need for 24/7 operations for distribution, to keep the shelves stocked, and the cooling loads to keep food preserved presented a large opportunity. Finally, note that the original program called for five sectors. However, as a result of discussions at the CPR in June and the second advisory committee meeting in mid July, the number of sectors was expanded to six as defined below.

- Commercial Office Building
- Hospitals/Healthcare/Nursing
- Colleges/Universities
- Jails/Prisons
- Hotels
- Food Processing/Warehousing/Grocery Stores

2.1.3. Site Evaluation

With the sectors defined, establishment of criteria for the evaluation of specific sites within the sector were established. Figure 9 defines the parameters.

As with the sector evaluation, the site evaluation had weighting factors associated with the site attributes that permitted quantification of the ranking. Much of this thought process and site evaluation occurred "off paper" by effectively prequalifying sites based upon many of these attributes prior to approaching. Combining the prequalification with the reality that there were insufficient sites that cooperated to even fill out the desired number in each sector, let alone be able to rank desirability and eliminate some, the site evaluations were never quantified.

<u>**Site Analysis**</u>

- **Suitable Size for Monitoring - Too large = $$$ equipment**
- **Proximity - Location relative to UCI, close proximity is easier to monitor and tend to problems**
- **CHP utilization – what specific CHP utilization is possible**
- **Existing On-Site Power Generation - Program calls for mix of site with existing DG**
- **Number of Circuits to Monitor - More circuits = more equipment**
- **Accessibility of Communications**
- **Site Cooperation/Risk Aversion**
- **Potential for CHP integration in future**

Figure 9: Site Evaluation Criteria

2.1.4. Sites Monitored

The process of sector and site definition and the subsequent engagement commenced in Q1 2007. Table 1 represents the result of the effort. The "institutions engaged" and individual sites represent the facilities that were approached for participation in the effort. The "monitored site" column represents the number in each sector for which, we obtained energy data. This represents roughly a 11.5% success rate in engaging facilities.

Table 1: Sector Breakdown for Site Participation

Sector (Total # Engaged)	Total Institutions Engaged*	Total Individual Sites*	Monitored Sites
Commercial Buildings	23	67	18
Hospital/Healthcare/Nursing	20	30	8
Colleges/Universities	10	20	9
Jails/Prisons	8	17	9
Hotels	24	25	4
Food Processing/ Warehousing/Grocery Store	10	90+	20
TOTALS	95	249	68

*Total Institutions reflects distinct participant, Total Sites reflects possibility of multiple individual sites under the auspices of one participant (e.g., individual campuses under a single administrative entity)

Certainly, there were many more opportunities for site monitoring than actually occurred. In many cases, the approached entities and sites were skeptical of the program and/or did not wish to be interrupted and bothered with the perceived support necessary for the program. Another factor that inhibited greater engagement was a limitation on the quantity of monitoring equipment that was available for sites distribution at sites. A summary of the experience with each sector is provided below

Commercial Office Building

In general, commercial office buildings are owned and operated by entities other than the occupants. Hence, engaging required identification and coordination with both the facility owner and the on-site company in the building. Of the 18 facilities monitored as commercial office buildings, five are owner occupied. Eight facilities are municipal buildings for the Los Angeles Internal Services Department (LA-ISD) through whom all monitoring access arrangements were made. Another eight facilities are owned by The Irvine Company through whom all monitoring access arrangements were made.

Hospitals/Healthcare/Nursing

This sector was moderately well represented in the program with an outreach to approximately 30 sites. Most private hospital facilities did not want to participate in the program. Hospital facilities were very wary of the proposed program; while initially embraced by many of the facility managers/directors of engineering, upper level approval was never forthcoming. A specific explanation was never provided by any facility other than "We are not interested". However the perception is that the hospital and healthcare industry is highly regulated and heavily scrutinized; as such, there is likely a desire to keep a low profile and not have additional information on hospital operations disseminated. In addition, the California, the Office of Statewide Health Planning and Development (OSHPD), a state agency that oversees hospital operations and safety, has not generally embraced DG/CHP. While the latter does not necessarily preclude energy monitoring of a facility, it does effect the perception of the value of the monitoring effort if the goal is to assess the application of DG/CHP in a sector that has a low likelihood of penetration/application.

The hospital facilities that did participate were Federal Veteran's Administration (VA) hospitals and one University of California "teaching" hospital. In addition, two health care clinics/centers operated by the LA-ISD.

Colleges/Universities

Three campuses were included in the study; University of California Irvine (UCI), Cal State University Northridge (CSUN), and Pasadena City College (PCC). These three represent the three levels of the College and University system of higher education in California; research university, educational college, and community college. For UCI, the campus as a whole was monitored as well as the energy needs of a variety of campus buildings that represent classrooms and research facilities. For CSUN and PCC, individual building performance was not assessed, only the campus as a whole. The community college sector was to have included the nine campuses of the Los Angeles Community College District (LACCD). Enthusiastic to participate, the access agreements were established; however, a combination of a lack of monitoring equipment and a general system wide construction effort including upgrades to Central Plant Facilities precluded inclusion of any sites in the program. It is expected that many of the LACCD facilities will be included as part of the Phase II effort.

Jails/Prisons

The Jail and Prison sector proved vexing. Access to the State Prison grid electric energy data was made available but it was subsequently discovered that (1) time resolved gas consumption data was not available and (2) generally, state jails and prisons are not air conditioned. We were able to gather electric data for a number of California Department of Corrections facilities in SCE territory through a web based account. The program was never able to physically install equipment at facilities. With just time resolved electric data available for jails and prisons, the value of this one aspect of the overall operation is dubious. Time resolved gas data for the likely highly cyclic nature expected (i.e shower, laundry, food preparation) was not obtained.

Access to Federal prison information was never established. Attempts through the Federal Energy Management Program (FEMP) office have not been successful.

One type facility that has been included in the sector is that of the State Mental Health Hospitals. While officially considered hospitals, these facilities are arguably a variation on prisons, with the majority of the patients criminals that are undergoing mental health evaluation or are not considered fit for trial. Unlike state prisons, the Mental Health hospitals provide lower density occupancy that included air conditioning. As State Prisons are expected to install air conditioning for prisoner comfort in coming years, the performance of the State Mental Hospitals provides a reasonable prediction of the coming needs. The program monitored Patton State Hospital (San Bernardino) and Metropolitan State Hospital (Los Angeles/Norwalk). Atascadero State Hospital has also agreed to participate but a lack of monitoring equipment, timing, and distance prevented their participation.

Hotels

Hotels hold promise as another very fine match for DG/CHP. Much like hospitals, the “hospitality” services of food and comfort lodging would seemingly translate to high energy intensity nearly 24/7. However, the sector is very competitive and reluctant to share or provide access to information on the day-to-day operations which could be considered competition sensitive. As such, while >25 hotel sites were approached, only four were monitored. And of the four, one was a high rise residential facility for the US Navy in San Diego that does not have the same level of hospitality service as a conventional hotel.

Food Processing/Warehousing/Grocery Stores

For the food sector, the efforts predominantly focused on grocery stores. Five grocery store “chain” were approached. Two chains agreed to participate. Stater Brothers agreed to provide access to four of its stores for instrumentation distributed between temperate and hotter climate areas. A second chain wishing to not be identified provided energy data that they monitored for the overall energy consumption as well as subsets that included lighting and refrigeration for 14 of their stores in both Southern California, Las Vegas, and Arizona (the latter two to provide high ambient temperature performance). An individual grocery store in the form of the US

Navy Commissary in San Diego, representative of a state of the art facility with many energy savings measures incorporated, was also included. Finally, a single large scale food distribution warehouse with multiple levels of refrigeration for food preservation was included. Two other warehouse operations were approached but declined to participate.

With regards to food processing, two Southern California food processing facilities were approached but declined to participate. Both specifically cited the competition sensitive nature of operations information. Given this information, no other sites were approached as part of Phase I. Information on other possible candidates in the sector has subsequently come to light; these will be approached as possible candidates for the Phase II effort.

3.0 Thermal and Electric Demand Measurements

Measurement of the thermal and electrical demand comprises the heat of this research activity. The general approach was to treat each facility as a black box and monitor the energy crossing the boundary of the black box from utilities (electric and natural gas) as well as energy provided by any on-site power systems such as photovoltaic and DG/CHP systems. For the latter, the energy crossing into the black box would also include any thermal energy, either hot water or chilled water, captured as a result of waste heat recovery from a DG /CHP system. Beyond the energy crossing the boundary of the black box, information on energy consumption within the box was of interest. Specifically, what were the loads for heat and cooling in support of the HVAC system and/or what were other process heating and cooling loads that could be partially or fully met with waste heat recovery and thermally activated cooling technologies (e.g absorption and adsorption chilling). As previously stated, the goal was to understand the effective and efficient application of DG/CHP to meeting building energy needs both thermally and electrically as well as assess the impact of the DG/CHP on the overall energy profile for the facility.

One of the key questions to address early on was the time scale of the monitoring. Initial thoughts were to have data gathered at very high resolution (on the order of 3-sec intervals). Measurements have shown very large energy demand spikes that are not captured in long interval monitoring. However, the Advisory Committee argued that (1) DG/CHP would not eliminate the grid, (2) the grid would be present to handle any high load transients, and (3) a DG/CHP system could not respond to perturbations that would occur in the order of seconds. Rather the Advisory Committee recommended a measurement interval of 15 minutes to correspond with the sampling rate resolution of utilities and the supplied grid electricity. This does provide a data manipulation benefit of reducing the number of lines of data to slightly more than 35,000 lines of data per year as opposed to more than 10 million lines of data at 3 second intervals.

The initial thoughts for the monitoring strategy at sites included:

- the installation of a power meter on the point of common connection between the facility and the utility electric grid,
- installation of a natural gas flow meter on the gas supply,
- and installation of a "btu-meter" on the hot water and the chilled water loops.

However, the reality of implementing the instrumentation resulted in some deviations from this scenario for the sake of safety, accuracy, expediency, and equipment supply limitations. One of the key issues encountered was the inability to install instrumentation in desired systems without requiring a facility interruption of shut-down, a prospect no site was willing to undertake. Re-evaluating the needs and availability of information from other sources, the deviations for the plan were specifically:

- Where ever possible, existing facility energy management system (EMS) data is utilized once it was confirmed to be accurate. No need to duplicate existing monitoring points and hardware.

- Use of utility recorded information via access to the facilities account and website based data. This has been implemented in virtually all cases, either through UCI having direct access to the account information or the facility providing the data from their utility account.
- Natural gas consumption is based upon monthly utility bills where available. With only one exception, there was not time resolved facility natural gas consumption information available. Southern California Gas, the gas utility for all of the sites in this program, does not provide time resolved metering as a general practice. We also discovered that there are rarely (never) any inherent access ports in the supply line where monitoring equipment could have been installed without a system shutdown and significant plumbing modifications made. As such, heating loads identified are the result of either (1) direct measurement of the hot water needs or (2) operational history of the boiler and assumptions of firing rate based upon nameplate data. Also, in general, the domestic hot water (DHW) consumption was not directly measured. For some facilities, the DHW was provided by part of the overall boiler/.hot water loop and could not be separated. For other facilities, hot water was provided by local electric hot water heaters at the point of use. The operation of individual tank hot water heaters was not monitored.
- Air conditioning systems based upon direct expansion (DX) systems (i.e. roof-top AC systems) did not fit the model of measuring chilled water flow and temperature rise. For facilities that utilized the DX systems, the electric energy consumed by the unit was monitored. Based upon nameplate data for the equipment, the fraction of energy associated with the compressor (not inclusive of the fan) was calculated and the manufacturer's coefficient of performance for the chiller utilized to ascertain the chilling load.

3.1. Utility and EMS data

Electric utility data for the primary electric feed to the facilities was obtained for virtually all facilities. This was accomplished either through (1) the facility providing the data via their gathering of the data from the Utility website (2) the data was available from the site's EMS data logs or (3) the facility provided UCI with account access and we recovered the data from the Utility. Direct measurement of the primary power was performed at only two sites (CO002 and CO011). The savings in equipment, time, and safety as well as the accuracy were all prime factors in this choice. The desired 15 minute interval data is gathered as a matter of course by the utility for all sites with time of use metering. All of the data obtained from the utilities was energy consumption (e.g. kw-hr) for 15 minute intervals.

In general, natural gas consumption, if obtained, was based upon monthly bills. SoCal Gas does not customarily monitor gas consumption based upon the time of day so utility based data is limited to monthly consumption. For most instances, this was not a major issue as large sources of heat (boilers, large hot water systems) were individually monitored. The belief is that the majority of the heating loads that would have been provided by natural gas were captured through the monitoring of the individual systems.

Where possible, EMS data was obtained for sites. Again, considerations of limited monitoring equipment, safety and service interruptions to the facility were prime considerations to opt for EMS data whenever it was available. Table 2 is a summary of the sites and whether data was obtained via monitoring or EMS data or a combination of both.

Table 2: Summary of Site Identification by Sector and Source of Energy Data.

EMS = Energy Management System source of data
Inst= Instrumentation installed for data

Commercial Office ID= COxxx		Hospitals/Healthcare ID=HHxxx		University/Colleges ID= UCxxx		Jails Prisons ID=JPxxx		Hotels ID=HOxxx		Food/Grocery Services ID=FGxxx	
CO001	EMS/Inst.	HH001	EMS	UC001	EMS	JP001	Inst	HO001	Inst	FG001	EMS / Inst
CO002	Inst	HH002	EMS	UC002	EMS	JP003	EMS	HO003	EMS	FG002	Inst
CO003	Inst	HH003	EMS	UC003	EMS	JP004	EMS	HO004	Inst	FG003	Inst
CO004	Inst	HH004	EMS	UC004	EMS	JP006	EMS	HO005	EMS	FG004	Inst
CO005	Inst	HH005	EMS	UC005	EMS	JP007	EMS			FG005	Inst
CO006	EMS	HH006	EMS	UC006	EMS	JP008	EMS			FG006	Inst
CO007	EMS	HH007	EMS	UC007	EMS	JP009	EMS			FG007	EMS
CO008	EMS	HH008	EMS	UC008	EMS	JP010	EMS			FG008	EMS
CO009	EMS			UC009	EMS/Inst	JP011	EMS			FG009	EMS
CO011	Inst									FG010	EMS
CO012	EMS									FG011	EMS
CO013	EMS									FG012	EMS
CO017	EMS									FG013	EMS
CO018	EMS									FG014	EMS
CO019	EMS									FG015	EMS
CO020	EMS									FG016	EMS
CO021	EMS									FG017	EMS
CO023	EMS									FG018	EMS
										FG019	EMS
										FG020	EMS

Many of the EMS data sets were complete and provided necessary information either directly or through extrapolation from known system parameters. It was interesting to note that there is little consistency in the EMS data fields or format; every facility has different priorities as to what they thought was critical to their facility's operations.

3.2. Equipment Installation

For sites that required instrumentation, a wide variety of monitoring equipment and recording equipment was utilized, depending upon the specific site needs and proximity of subsystems.

3.2.1. Electric Energy

Electric energy to the facility from utilities was anticipated to be monitored independently at each site. However, it was quickly determined that instrumenting of the main electric feed would be highly problematic; rather, in virtually all cases, existing and installed electric meters (utility or site submetered) would provide sufficient information. The utility meters were accessed through web based data provided by the utility to their customers. The data varies somewhat from utility to utility but in general, information on energy consumption at 15 minute intervals was available. This is the same data set that the utilities use for billing of the customer. As such, the accuracy of the meter can be considered revenue grade certified with an accuracy error of <1% of the reading. Sites either provided the data to the program directly or granted permission (via account name and password) to the program to acquire the data directly. For some sites, primarily those with photovoltaic systems, on-site power generation was also monitored by the utility and available through the same utility supported data base.

Beyond the grid electric, the need for monitoring of electric power consumption was nearly universal at all sites. This system proved to be the easiest to implement and could, with care, be installed with no service disruption and with no facility alterations. Electric system monitoring consumption was used to monitor the energy flow for chillers, DX air conditioners, refrigeration systems, and submetering of buildings. In two cases, these systems were used for monitoring the primary electric energy flow into the facility. Two systems are available for use, depending upon the site needs but both utilized the same principles of current transformers (for this study, split core transformers that permitted installation without lift the leads (i.e. without service disruption)) monitoring the current flow and voltage taps monitoring the voltage on the supply conductors. Without exception, all of the electric service to the facilities and to the primary loads monitored is 3-phase. The service voltage varied among site but was either 208 volt or 480 volt.

Dent Elite Pro Power Meter

The Dent Elite Pro power meter[19]was the primary system of choice. The system is very flexible for a wide variety of electric service configuration and voltages and with proper choice of the Dent proprietary current transformers, offers a wide range of power monitoring levels. The system operation is configured though a computer interface that allows the user to chose electric circuit configuration parameters, specify the current transformer size, the logging rate and the parameters of interest with includes individual leg and cumulative data on voltage and current (average, max, min) as well as power (kW, kVA, kVAR, power factor). The Dent Elite Pro meter also provides on board data logging. When equipped with an extend memory option (as was done for this program), the units could store more than 2 years worth of data (depending upon the number of fields being recorded). The data is retrieved from the meter via the same communications system used for configuring the system through the computer. The stated accuracy of the Dent Power Meter for energy/power values is <0.5% of reading

Flex-core Power Meter

The Flex-core power meter[20] (model WL50-346-500K) was identified as a lower cost alternative to the Dent Elite Pro Meter. This meter is set for a fixed voltage and current limit and does not provide on board data logging. The device provides a pulse output corresponding to a specific energy. As such, this meter was limited to applications wherein additional data was to be monitored and logged through the data logging system (see below). As a low cost alternative, the units proved to be reliable if not flexible and provided relief from the shortfall in the number of Dent meters that were available. The stated accuracy of the Flex-core Power Meter is <1% of reading.

[19] Dent Meter, Bend OR
[20] Flex-Core, Milliard, OH

3.2.2. Water flow / btu meters

To monitor the performance of heating and cooling loops that were otherwise not instrumented, a water flow meter and temperature sensors to measure the change in temperature of the fluid were used. Knowing the mass flow of the water (through the measured volume flow) and the change in temperature, the energy change could be calculated.

Emco ST 30 Sono-Trak meter.

The primary goal of the instrumentation from the perspective of the facility was to not disrupt service. The Emco ST30 Sono-Trak meter[21] is a non intrusive ultrasonic flow meter that is mounted to the outer surface of the pipe containing the fluid. Ultrasonic waves are "bounced" between two transducers that are set a specific separation (dependent upon the fluid, pipe thickness, and the pipe diameter), both with the flow and against the flow. Through analysis of the received frequency, the bulk fluid velocity can be calculated. Further, the system can, through the input of pipe parameters, will calculate a volumetric flow rate and accumulate total volume reading. The system provides a 4-20 mA output proportional to the flow rate that must be recorded via the data logger. The stated accuracy of the Emco ST 30 is <2% of flowrate reading in a field application; repeatability is <0.5%

Two downside issues with the system were

(1) the need to establish a uniform flow through the metering field. This mandated a minimum length of straight uniform pipe upstream and downstream of the monitoring point. This proved challenging in many installations given the typically tight space within mechanical rooms and the circuitous routing of the plumbing

(2) the need to have the meter mounted directly to the pipe for proper acoustic coupling. This required the removal of installed insulation on the piping. Great care was required to minimize the amount of material removed and to retain the insulation so that it could be replaced at the conclusion of the monitoring effort.

The meter proved to be reasonably reliable but some instances of erroneous readings were observed, perhaps the result of contamination or more likely air bubbles in the flow field.

Temperature Monitoring.

In conjunction with the flow meter, the change in fluid temperature entering and exiting either a boiler or a chiller is necessary to calculate the change in energy. In the spirit of non-invasive measurements, surface mount devices were incorporated. These were either 100-ohm RTD (resistance temperature devices) with an adhesive pad substrate or a magnetically mounted type T thermocouple. Both were connected to transmitter devices that converted their inherent signal to a 4-20 mA signal that was logged. One interesting and unexpected development was an electrical interference for the magnetic mounted thermocouple; a single device could be mounted and accurate data received; however, two or more devices that were electrically connected (i.e. the piping is an electrical conductor) resulted in erroneous readings. We were

[21] Engineering Measurements Co., Longmont CO

never able to determine the reason but assumed it was the result of ground loops or magnetic mount induced electromagnetic interference (EMI).

For the low profile RTD, the device was tucked under some of the existing pipe insulation; the expectation being that in near steady state with insulation, the surface temp of the pipe would be nearly equivalent to and track the changes in the fluid temperature. For the larger thermocouple mount, insulation was packed around the device to minimize any heat loss through the surface of the piping.

For both the thermocouple and the RTD, standard "commercial" tolerance devises were utilized. As such, typical errors for RTD's and thermocouples apply.

3.2.3. Gas flow

Overall natural gas consumption at a facility was typically limited to readings provided on monthly utility bills. Typically, natural gas provided by the utility is not "time of use" sensitive and as such, the installed meters do not normally have a means for providing time resolved consumption history. Further, natural gas supplies to a facility are the property of the utility until the discharge point of the meter so alteration to the plumbing to permit installation of time resolved metering upstream of the meter is not viable. Finally meter discharge is typically positioned immediately adjacent to the building. Once entering the building, the plumbing is generally not accessible and does not include access ports. All of this is to state that for all facilities in this study, any facility natural gas consumption reported is the result of monthly total consumption readings.

The lack of time resolved facility wide gas consumption is not a major issue. Internal systems that would utilize the waste heat for heating purposes such as HVAC heating and process steam are monitored separately and individually and an assessment of the heating needs documented. Other gas consumption that would have been a part of the overall values entering the facility (i.e. kitchen cooking, laundry dryers, etc) would not have been loads that could have been directly addressed by a DG/CHP system. Hence, even without a fully time resolved overall natural gas consumption history, the necessary heating needs that would be addressed by a DG/CHP system have been captured.

Sage SGI[22] insertion thermal mass flow meters were used to monitor natural gas flow where necessary. The meter utilizes the principle of heat loss from a heated temperature device to calculate the true mass flow of gas which is correlated to and reported as a "standard" volume flow. The device provides a 4-20 mA signal proportional to the flow rate and is recorded by the data logger. The stated accuracy for the Sage SGI meters is < 1% of reading with a repeatability of 0.2% of full scale value.

The Sage meters were purchased pre-calibrated for natural gas. They were rated for piping from 2" ID minimum to up to 18" diameter. The thermal sensors are designed to be located in the center of the pipe flow. As with the water flow meter, pipe parameters are input to correlate the mass flow to the volumetric flow. Also like the water meter, the device wants uniform flow

[22] Sage Metering Inc, Monterey CA

field upstream and downstream of the meter. A proper section of pipe was usually easier to identify than the water meter. However, unlike the water system, the gas flow meter was inserted into the flow. This required locating or installing an access port in the piping as well as a both a gas service shutdown. The use of these meters was limited to facilities with on site fuel based distributed generation system (i.e. microturbines or fuel cells) that did not have existing fuel monitoring. We were never able to identify an application of the meter to monitor facility level gas flow rates.

3.2.4. Data Logging

For all signals from devices other than the Dent Elite Pro power meter, data was retrieved and logged with Campbell Scientific Data loggers[23]. Both CR 1000 and CR 800 devices were utilized depending upon the number of channels to be logged. Both devices are capable of logging voltage signals and, with external shunt resistors, current signal inputs. They are also able to monitor pulse inputs (such as those from the Flex-core power meters). While capable of remote access via phone modem or wireless modem connections, all data was manually downloaded from the devices. The sampling frequency can the internal memory provided many months of data capacity.

The Campbell Scientific data loggers utilize 13- bit A-D converters (± 0.06% resolution) for storing the analog voltage signals that are compatible with the logger. For current signals, precision resistance "shunts" of 100 ±0.01% resistors are used to convert the signal to voltages.

For the parameters being measured as part of this program, the precision of the sensors is in line with the ASERTTI field testing and long term monitoring protocol specifications (Table 3).

Table 3: Comparison of Measurement Accuracy with ASERTTI Protocols

Parameter	Units	ASERTTI Field Test	ASERTTI Long Term	CEC Energy Monitoring
Electric Power	Kw-hr	± 0.6% of reading	Value of ±0.25	± 0.6% of reading
Gas Consumption	Scf or MMbtu	±1% reading	±1% full scale	±1% of reading
Waste Heat				
Fluid Flow Rate	Gallons per minute	±1% reading	Calculated btu recovery based upon all parameters: ± 10%	±2% reading
Fluid Temperature	° F	±0.6 °F of temperature		±1 °F of temperature
Fluid density and specific heat	lb/cu-ft Btu/lb	±0.11% ±0.16%	± 0.2% ±0.1%	Assumed to be water

[23] Campbell Scientific Inc., Logan UT

4.0 Data Base Generation

4.1. Data Base Architecture

The data base is oriented around the structured query language (SQL) protocol. SQL is inherently suitable for large data base storage and manipulation. The data base will consist of a single level table of data identified by sector and site identification serial number. The structure of the table and the characteristics of the SQL protocol will permit interrogation of the data for individual sites as well as comparative interrogation within sectors and across sectors.

For the monitoring effort, the monitored facilities are treated as a "black box" in which energy crosses the boundary in the form of grid electricity and natural gas. Additionally, the energy needed to provide HVAC cooling and heating (i.e. occupant comfort) and process cooling and heating (i.e. process cooling and heating) are monitored coincident with the energy crossing the black box boundary. The cooling and heating components are expected to be energy loads that can be addressed with waste heat recovery strategies from DG systems. A comparison of the heating and cooling loads versus the electric energy needs help to identify the DG technology that is best matched to the needs. The data base will include ambient condition information, energy consumption data for the site including energy input to the facility crossing the facility boundary (i.e. natural gas and grid supplied electric) as well as any on-site power generation through the application of fuel based systems (i.e. microturbines, fuel cells) or non-fuel based (i.e. photovoltaic), and information on the use of the energy within the facility boundary that could potentially be met through the application of waste heat recovery, specifically HVAC heating and cooling, DHW heating, and any process heating and cooling needs.

Aside from data obtained from the monitoring effort itself, the data base includes ambient conditions (dry bulb temperature and relative humidity) to permit trending and comparison of the energy needs with respect to the prevailing weather conditions. Finally, the data base will include a number of parameters that are calculated based upon site characteristics; that is, several data points will be normalized to permit comparison of the energy intensity of the facility within and outside of its sector with other facilities.

4.2. Fields

As a result of the monitoring effort of this program, a time dependent data record is obtained from each site for the total energy consumption for the facility as well as the energy requirements for HVAC needs and process loads. In addition, for the sites that have an existing on-site generation/co-gen installation, information on the energy produced, energy consumed (if any), and the amount waste heat recovered will also be recorded.

Many of the sites in this effort have multiple inputs for the desired parameters. For instance, some installations have multiple electric meters feeding the facility, have multiple air conditioners, and/or have multiple distributed generation systems on site. The disparate and unique nature of each site's energy monitoring history would make interrogation of the final SQL data base cumbersome and comparison virtually impossible. As such, the individual data sets are processed and summarized into single "totals" for presentation in the SQL database in a consistent format with consistent field headings.

In addition to processing the data from multiple monitoring points into a consistent set of facility parameters, the data will be further processed to provide information on the sub-metered loads as compared to the total energy. Further processing of the data will result in reporting of some benchmark data normalize the energy consumption based upon some facility characteristics such as square footage, occupants, and/or number of rooms.

For those sites with existing on-site generation/co-generation systems, one goal so the program is to provide time resolved history of system electrical and, is so outfitted, waste heat thermal recovery output as well as fuel to electric and fuel to thermal efficiencies. Since their presence offsets the facility's electric energy consumption from the grid, any on site energy production will be added to the monitored energy consumption from the grid and reported as the total site energy requirement. The contribution of the on-site power generation will be tabulated individually as well as a calculated percentage of the electric power to the total demand. Similarly, if the contribution of a waste heat recovery system offsets a chilling or heating load provided by a more conventional electric chiller, boiler, or furnace, the contribution of the co-generation will be added to the monitored chiller or heater performance as appropriate to provide a total facility chiller/heater/process demand for the facility. As with the electric power, the contribution of the co-generated heating/chilling/process load will be reported individually as well as calculated percentages of the total demand.

4.2.1. Site Reporting Fields

The specific data fields that will be reported in the SQL data base are presented below. The units and format of the data is presented in the "[ ]". Any additional comments relative to the parameters are presented in italics within the "( )". A total of 64 columns of data will be populated

1. **Site ID**; [sequence number]
2. **Date Stamp**; [date/number]
3. **Time Stamp**; [time number]
4. **Ambient Temp**; [deg F, number]
5. **Relative Humidity**; [%, number]
6. **Total Electric Energy** for time interval; [kw-hr, number] *(summation of any individual meters for the site and any on site power generation from combustion, fuel cell, and/or PV)*.
7. **Total Gas Consumption** for time interval [btu, number]; *(for many facilities, the gas consumption will be quite small, serving essentially DHW and some HVAC. Depending upon magnitude of number, this may be measured or a calculated number based upon heat production or system operation and nominal firing rate)*
8. **Total HVAC Chilling** for time interval; [btu, number] *(summation chilled water and/or direct air cooling)*

9. **Total HVAC/DHW Heating** for time interval; [btu, number] *(summation of all heating for HVAC and domestic hot water)*
10. **Total Process Chilling** for time interval; [btu, number] *(summation of any chilling loads outside of HVAC (e.g. refrigeration for grocery stores))*
11. **Total Process Heating** for time interval; [btu, number] *(summation of any heating loads outside of HVAC and DHW (e.g. process steam for sterilization); note that this would only be associated with systems that make the steam or hot water directly. Many restaurants/hotels/hospitals take the same hot water used for HVAC and locally heat for the need such as internal/integral electric heater for dishwasher or autoclave. We cannot monitor these minor loads)*
12. **Total Fuel Based On-Site Electric Power Generated** for time interval; e.g. microturbine, fuel cell; [kw-hr, number]
13. **Total Non-Fuel Based On-Site Electric Power** for time interval; e.g. solar, wind; [kw-hr, number]
14. Total end use waste heat recovery for time interval; [btu, number], *(this would be a measure of the end use of the waste heat recovery accounting for any losses/inefficiencies in conversion of waste heat to a beneficial commodity)*. Applicable for:
    - **Total Waste Heat to Hot Water/Steam**; [btu, number]
    - **Total Waste Heat to Chilling**; [btu, number]
    - **Total Waste Heat to "Other"**; [btu, number] *(dehumidification, direct to process use, others to be defined)*
15. **Efficiency Fuel to Electric** [% on LHV, number] *(LHV = lower heating value of fuel)*
16. **Efficiency Fuel to Electric + Thermal**; [% on LHV, number], *(combine the total electric energy with useful thermal recovery in consistent units)*
17. Percentage/Ratio of chill or heat to total electric energy consumed; [%, number] *for time interval (all calculated values))* (Note, limiting to electric since this would be the parameter of interest and parameter offset with the application of DG technologies)
    - **HVAC Chill/Total Electric Energ**y
    - **HVAC Heat/Total Thermal Energy**
    - **Process Chill/Total Energy**
    - **Process Heat/Total Energy**
18. Normalized loads per square foot for time interval *(each parameter divided by facility sq-ft)*
    - **Total Electric** [kw/sq-ft, number]
    - **Total Energy** [btu/sq-ft, number] (gas and electric in consistent units)
    - **Total HVAC Chill** [btu/hr/sq-ft, number]
    - **Total HVAC Heat** [btu/hr/sq-ft, number]
    - **Total Process Chilling** [btu/hr/sq-ft, number]
    - **Total Process Heating** [btu/hr/sq-ft, number]
19. Other Normalizations for time interval: Same parameters as above but normalized as follows for each of the sectors:
    - Colleges/University: *(normalized per number of students)*.

- Hospitals/Nursing Homes: *(normalized per number of beds)*
- Hotels: *(normalized per number of rooms and/or number of beds).*
- Jails/Prisons: *(normalized per number of actual inmates*)
- Commercial Buildings: *(normalized per nominal number of occupants/employees*)
- Food/Grocery: *(no other normalizations expected)*

4.2.2. Site Characteristics Template

Beyond the monitored site energy data, site characteristics were gathered to provide background and the basis for comparison with other facilities. Figure 10 represents the site template utilized and completed for site CO001 (commercial office site 1). Note that very specific information was requested regarding utility accounts and costs. In the end, no site provided this information. In as much as rates are fluid and specific account information is not immediately relevant to the study, this was not considered an issue.

The site templates did request information on the gross square footage of the facilities served by the electric meters and the other monitored loads. Information on occupancy was also requested. However, in many instances, such as hotels and commercial office, this number varies widely and continuously. Of note is the effect of the economic duress that was prevalent during the period of this effort. Some of the commercial office space and the hotels that participated experienced below normal occupancy levels and as a result, the data obtained can be considered skewed to lower levels or perhaps higher per capita levels than might otherwise be the norm.

Site ID CO001
Record / Site Number 1
Company Name SCAQMD Headquarters
Company Address 1 21865 E. Copley Dr
Company Address 2
City Diamond Bar
Zip Code 91765
Contact 1 Name Gary Heiss
Title Facilities Manager
Contact 1 Phone (909) 396-2297
E-mail gheiss@aqmd.gov
Contact 2 Name
Title
Contact 2 Phone
Email

Facility Information

Facility Type Commercial — Hotel, College/Univ, Hospital/Health, Jail/Prison, Commercial, Food Gro. or Food Ware
Facility Size 350,000 — Total Square Footage
Number of Floors 6
Floor Sq Ft 58,300 — Average floor space per story
Fac No. People 1000 — For College/Univ, Jail Prison, and Commercial, est of typical number of people on site
Fac No. Rooms n/a — For Hotel, Hospital/Health, the number of rooms/beds
Investment Criteria — Payback terms (years or % ROI)
Facility Comments Corporate Headquarters. Facility has two MTG installations (4 turbines and 3 turbines) with waste heat recovery for hot water needs

Utility Information

Fac Elect. Utility SCE
Acct No
Acct Manager
Phone
Elect Srvc volts_phase 480 volt / 3 ph
Rate TOU-8
Avg Elect Cost $ / kw-hr
Nom Feed Power
Peak Feed Power

Fac Gas Utility Sempra
Acct No
Acct Manager
Phone
Gas Press psig
Rate GN-10
Avg Gas Cost $ / MMbtu
Avg Gas Consumption MMbtu / month

HVAC DHW Systems

Cooling type Electric Chillers — Type of System: Electric DX, Electric chiller, Absorption Chiller
Cooling No Units 2
Cooling Total Size 1540 tons
Cooling COP 3.5
Is COP Estimated? Y — Y / N
Cooling Power (electric) 1540 kW
Cooling Operation per week 75 — % Estimate of Duty Cycle

HVAC Heating Type Hot Water Boiler
Heat No Units 2
Heat Total size 4.8 MMBtu/hr
Heat Efficiency 90
Heating Operation per week 15 — Estimate of Duty Cycle

Hot Water (domestic) type Elect Water Heater
HW temp 140 — deg F supply temp
HW size — MMbtu/hr
HW Operation per week — Estimate of Duty Cycle
HVAC Comments

Other Process Systems

	Steam	Refrigeration#1	Refrigeration#2
Type			
Number			
Temp [deg-F]			
Press [psig]			
Total Size		tons	
Gas Flow / Power	SCFM	kW	
Efficiency/COP	%		
Duty Cycles			

Process System Comments

On Site DG

	DG System 1	DG System 2	DG System 3
Type	MTG	MTG	
Number	3	4	
Total Gen. [kW]	195	240	
Use of Waste Heat	hot water	hot water	
Waste Heat [MMbtu/hr]	1.2		
Exhaust Height [ft]	10	10	
Exhaust Dia.[in]	12	12	
Exhaust Temp [deg-F]	350	350	

Figure 10: Site Characteristics template example

4.3. Preliminary Review and Comparison of Energy Profiles

4.3.1. Commercial Office

The results for a large commercial office facility are present in Figure 11 and Figure 12. This facility, located in Irvine, CA, has total floor space of 1.12 million square feet spread over 5 buildings and a total of 54 stories. The facility is unique in the application of a chilling only central plant of 1500 tons total capacity as well as a thermal energy storage capability for chilled water of 12,500 ton hours. Space heating and domestic hot water needs are addressed through local electric resistance heating.

A typical summer day is shown in Figure 11. The electric energy for the site at 15 minute intervals (kw-hr) inclusive of the chilling loads is shown as is the building chilled water demand for HVAC needs.

As a possible scenario of application of a DG/CHP system, assume that the chilling demand could be met with a double effect absorption chiller sized for 300 tons coupled with a 1.5 MW gas turbine. Further, assume that the gas turbine has a minimum load capability of 70% of the full load (i.e. 1.0 MW). The result of this scenario is presented in Figure 12. Note that the turbine would only operate during typical business hours (6 am to 6 pm) but during that time, all of the chilling loads are met either through the thermal energy storage system or the absorption chiller, the grid imported peak electric power is reduced by 87% and the electric energy is reduced by 62%. Another possible scenario, not presented here, is application of the DG/CHP to meet the 24hr baseline demand (i.e. provide electric power and cooling overnight to recharge the thermal energy storage tank). However, the impacts to the grid during the period of highest need (i.e. peak energy demand) and the resultant cost savings would be less than the scenario presented.

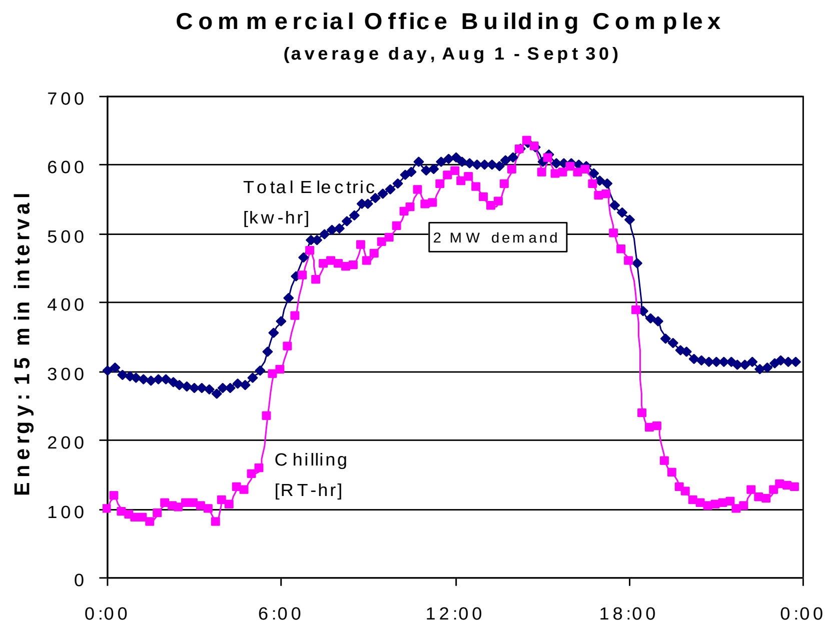


Figure 11: As measured Typical Summer Energy Profile: Commercial Office Building

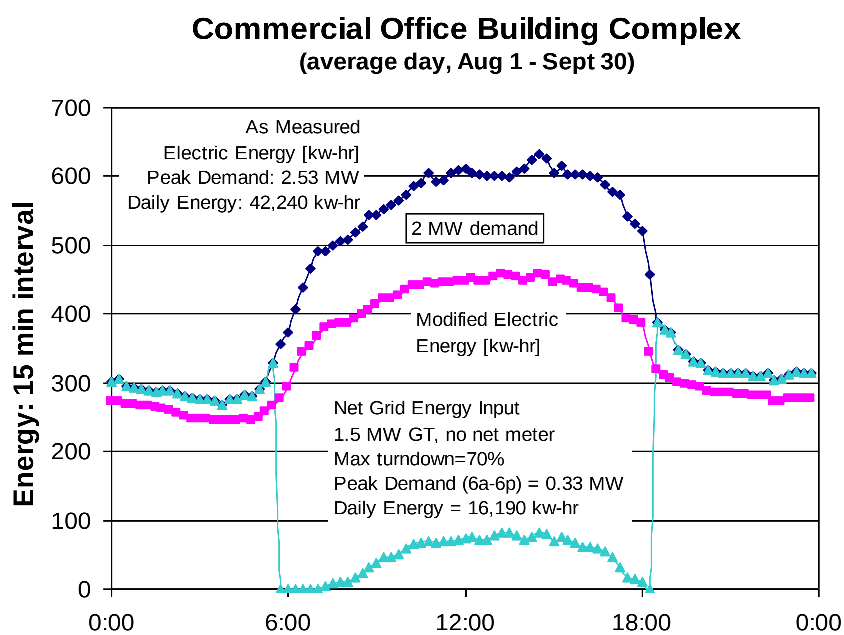


Figure 12: Energy Profile after Application of DG/CHP: Commercial Office Building

4.3.2. Grocery Store

The results of the monitoring of a medium size grocery store during a typical summer day are presented in Figure 13 and Figure 14. This store, located in Laguna Hills, CA, has a nominal sales floor space of 29,000 sq-ft and ancillary space of approximately 14,100 for a total building size of 43,100 sq-ft. The facility has an installed capacity of air conditioning of 40 tons , subcooling of 20 tons, and medium temperature refrigeration (> 20 deg F) of 35 and low temperature refrigeration (<20 deg F) installed capacity of 22 tons. The results of the energy monitoring indicated that the subcooling and medium temperature loads are nearly constant while the air conditioning load, owing to the relatively temperate climate and the spill over cooling from the other refrigeration systems operated less than 10% of the time.

Thermally activated cooling (e.g. absorption cooling) is limited to minimum temperatures of 40 deg F for lithium bromide systems and as low as 0 deg F for ammonia based systems. The former are typical for HVAC system applications but, in the case of grocery stores would also be applicable for subcooling where the temperatures needed are 60 deg F. For the ammonia based systems, the technology is well understood in as much as these were the first application of absorption technology; however, the danger associated with ammonia and the development of lithium bromide systems has resulted in a very limited number of suppliers of ammonia absorption chiller technology.

As a possible scenario of application of a DG/CHP system, assume that the medium temperature chilling demand which includes the air conditioning, and sub cooling loads could be met with an array of single effect absorption chillers sized for 75 tons total coupled with a 150 kW reciprocating engine (note that is presumes that an ammonia absorption chiller of could be applied for the medium temperature cooling needs in the 20 – 40 F range). Further, assume that the reciprocating engine has a minimum load capability of 50% of the full load (i.e. 75 kW). The result of this scenario is presented in Figure 14. Note that the engine would be able to operate all day, neither exporting electric power nor exceed the lower limit of its operating range. The DG/CHP would be able to meet virtually all of the energy needs for the facility through the day, only drawing upon the grid during the peak mid-day periods. The grid imported peak electric power is reduced by 88% and the electric energy is reduced by 95%. Further, assuming specific utility costs (Electric: SCE TOU-GS3, natural gas: $5.00 .MMbtu), a nominal utility cost savings of approximately $7000 (or 60% over the grid connected scenario) is possible.

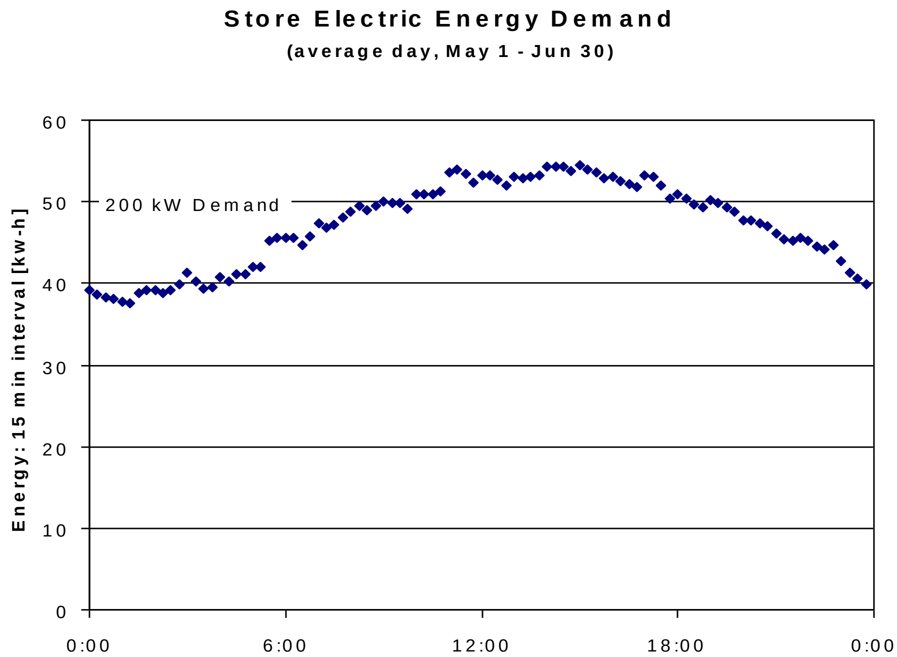


Figure 13: As measured Typical Summer Energy Profile: Grocery Store

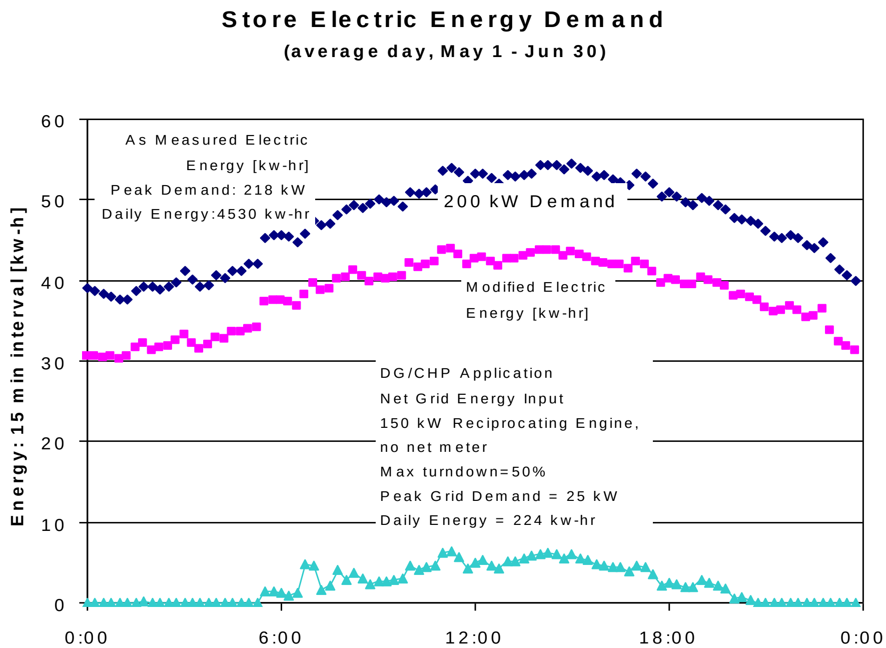


Figure 14: Energy Profile after Application of DG/CHP: Grocery Store

5.0 Comparison of DG/CHP Utilization

5.1. Sites Identified

The original intent for this program was to identify approximately equal numbers of facilities without on site DG/CHP as with. Efforts in establishing site candidates did address this goal but, as it turned out, only three sites that agreed to participate in the program had on site DG/CHP systems. Specifically, these sites were:

- South Coast Air Quality Management District (SCAQMD) headquarters: 435 kW total; two installations with seven microturbines total – one 3 x 65 kW and one 4 x 60; both with waste heat recovery for hot water
- California State University Northridge (CSUN): 1 MW total fuel cell installation (four units) with some waste heat recovery for hot water. – 692 kW photovoltaic also on site.
- Pasadena City College (PCC): 240 kW total (4 x 60 kW) waste heat recovery for absorption chilling
- UC Davis Medical Center (UCDMC): 26 MW gas turbine/steam turbine combined cycle installation with waste heat recovery for additional electricity (steam turbine), HVAC heating and chilling (via absorption chiller), domestic hot water and process steam.

For the DG/CHP systems, fuel consumption, net electric power output and waste heat recovery/utilization was monitored on the program consistent 15 minute intervals. Each site has some unique features in their installation as described.

5.1.1. SCAQMD DG/CHP

The SCAQMD has two installations of turbines. One comprised of a set of four, Capstone 60 kW turbines dates from approximately 2002. The units are grouped as two sets of two, each set having the exhaust gas feeding a single MicoGen waste heat recovery heat exchanger to provide hot water.. The second system is comprised of three Capstone 65 kW units with the exhausts ganged together and feeding a single Cain waste heat recovery heat exchanger to generate hot water. The hot water generated is used for facility HVAC heating needs throughout the year; the Central Plant chillers providing HVAC cooling and dehumidification with local reheat for comfort. This loop is parallel with the facility's boiler system and offsets operation of the boiler.

5.1.2. CSUN

The CSUN campus is progressive in the application of DG/CHP as well as other renewables. They have a series of photovoltaic panel s as parking shade covers and generating nominally 692 kW of power. They also have a series of six, 30 kW microturbines installed in the 2002 time frame that currently operate on a very limited basis during to preheat boiler feedwater for the campus loop. Due to the limit operation of the system, it was not monitored or considered in this study.

CSUN does have a Fuel Cell Energy 1 MW molten carbonate fuel cell system (four DFC 300 units with an installed rating of 250 kW each). This system was installed at a satellite central plant from the main. Due to campus growth, additional cooling was necessary; a satellite chilling station was deemed appropriate. The 1 MW fuel cell was installed as the primary source of power for the new chillers at the remote plant. The system was designed and installed with exhaust waste heat recovery to support campus hot water needs too. Uniquely, the installation has a two step waste heat recovery process to gather both the sensible heat from the exhaust (i.e. change in temperature of the exhaust) as well as the latent heat (i.e. the heat recovered from the condensation of the moisture in the exhaust as the exhaust temperature drops below the dew point). This allows for extremely high overall system efficiencies.

5.1.3. PCC

PCC has two MTG installations. One consisting of two Capstone 60 kW microturbines is used on a limited basis to provide heating of an athletic pool. Due to its intermittent operation (only seasonal and only then on a limited basis through the day), it was not considered in this study. The second installation is comprised of four Capstone C60 units. The exhausts for the four units are ganged together and used to drive a direct exhaust fired absorption chiller (Trane 100 ton). For this installation, measurement of the waste heat captured from the microturbines was not possible (no readily available means of measuring the exhaust flow and change in temperature). Rather, the performance of the absorption chiller was monitored. As the beneficial by-product of the waste heat recovery, it does provide a direct measure of the value of the waste heat recovery. However, the data relative to the quantity of waste heat recovered will be skewed based upon the coefficient of performance of the absorption chiller.

5.1.4. UCDMC

UCDMC was the only site in the program that derived all of its power from its on-site generator. The facility is connected to the grid but for all but nominally < 1% of the year, the site generates all of the needed utilities. At some points, through agreement with Sacramento Municipal Utility District (SMUD), there is some back feeding to the grid but this too is rare (<1% of the time annually). The exhaust waste heat is directed to a heat recovery steam generator (HRSG) to provide a flexible waste heat stream that can be used to generate additional electric energy via a steam turbine generator. There are 11,500 tons of installed chillers with room to install 4,100 additional tons. The chilled water system is a 16 degree 42/58 system. Sixteen degrees is obtained during peak conditions. There are 90,000,000 BTU's installed heating capacity. Heating water is 237 degrees supply to the campus. This is a 100 degree 240/140 system. Process steam is delivered to three Research buildings and the Hospital complex at 100 psi. Process steam is used for cage/cart washers, sterilizers and the Hospital kitchen. Current peak load is 4000 lbs/hr.

5.2. DG Operational Monitoring

The operation of the DG / CHP systems was assessed in much the same manner as other energy systems at each site. The aforementioned power meters (either Dent or Flex-Core) were installed at the point of common connection for the DG system so as to measure the net power output (accounting for any parasitic losses associated with gas compressors). Natural gas flow was monitored with either existing meters at the sites (SoCal Gas typically requires the installation of time resolved meters for DG installations) or the installation of the Sage insertion meter. For waste heat recovery, temperature change of the working fluid was monitored with either surface mounted thermocouples or RTDs while flow rate was monitored via the EMCO Sono-Trak meter and cross correlated/verified with logged operation of the pump motor and pump rating.

5.3. Utilization Results

5.3.1. AQMD

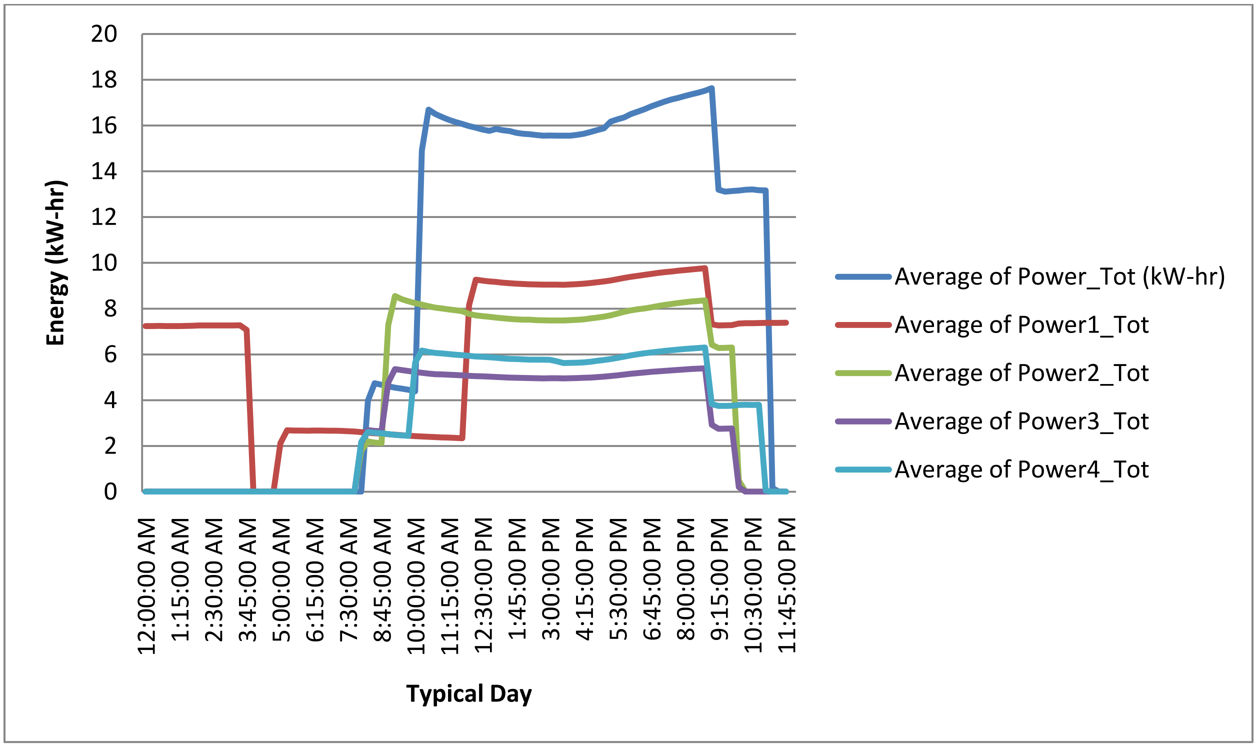


Figure 15 AQMD MTG Installation: Typical Energy Profile; Oct-Dec 2008

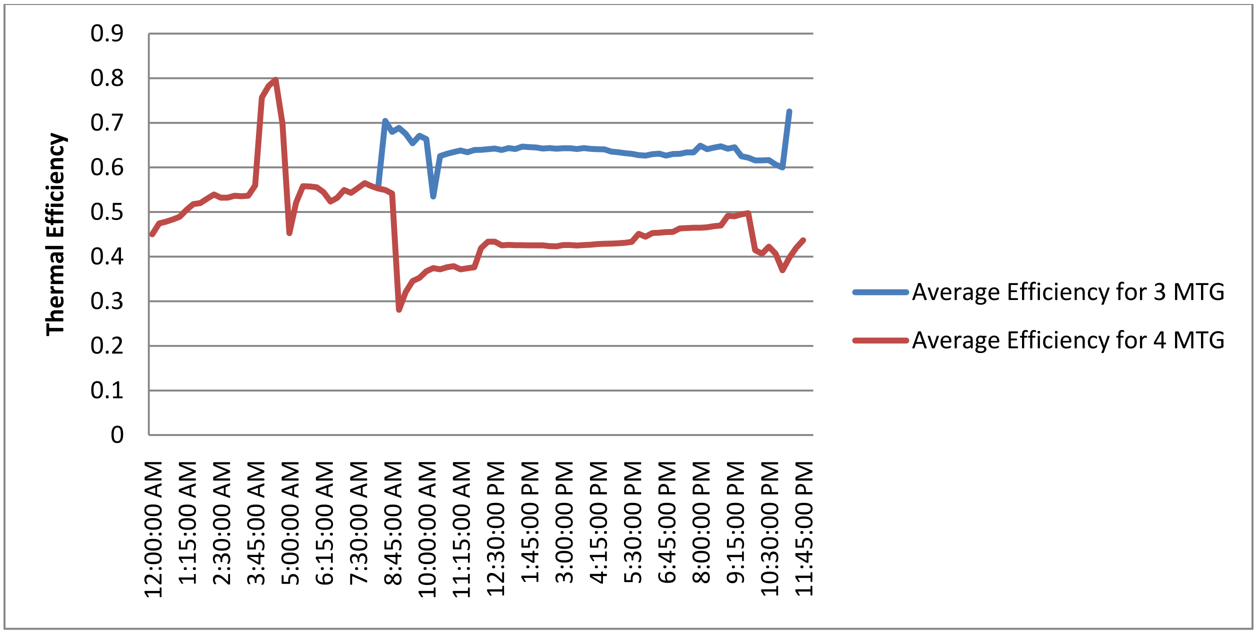


Figure 16: AQMD MTG Installation: Typical Overall Thermal Efficiency Profile: Oct - Dec 2008

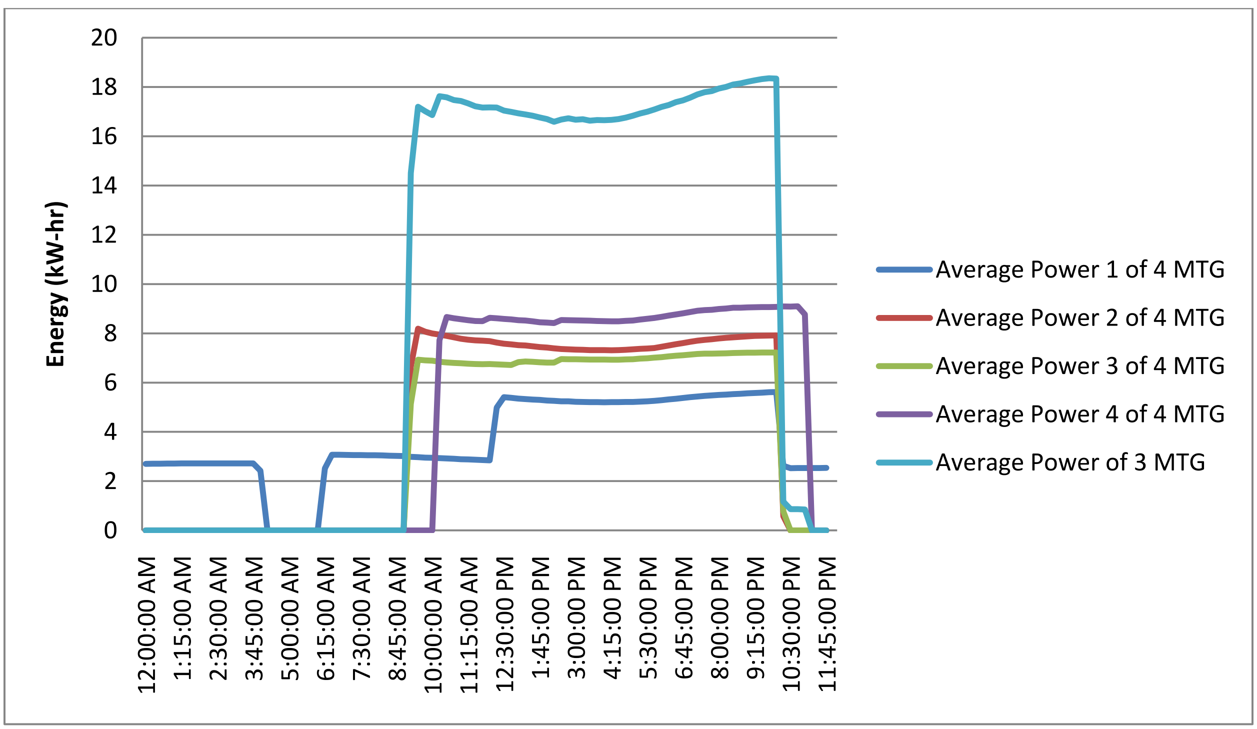


Figure 17: AQMD MTG Installation: Typical Energy Profile; Jan - March 2009

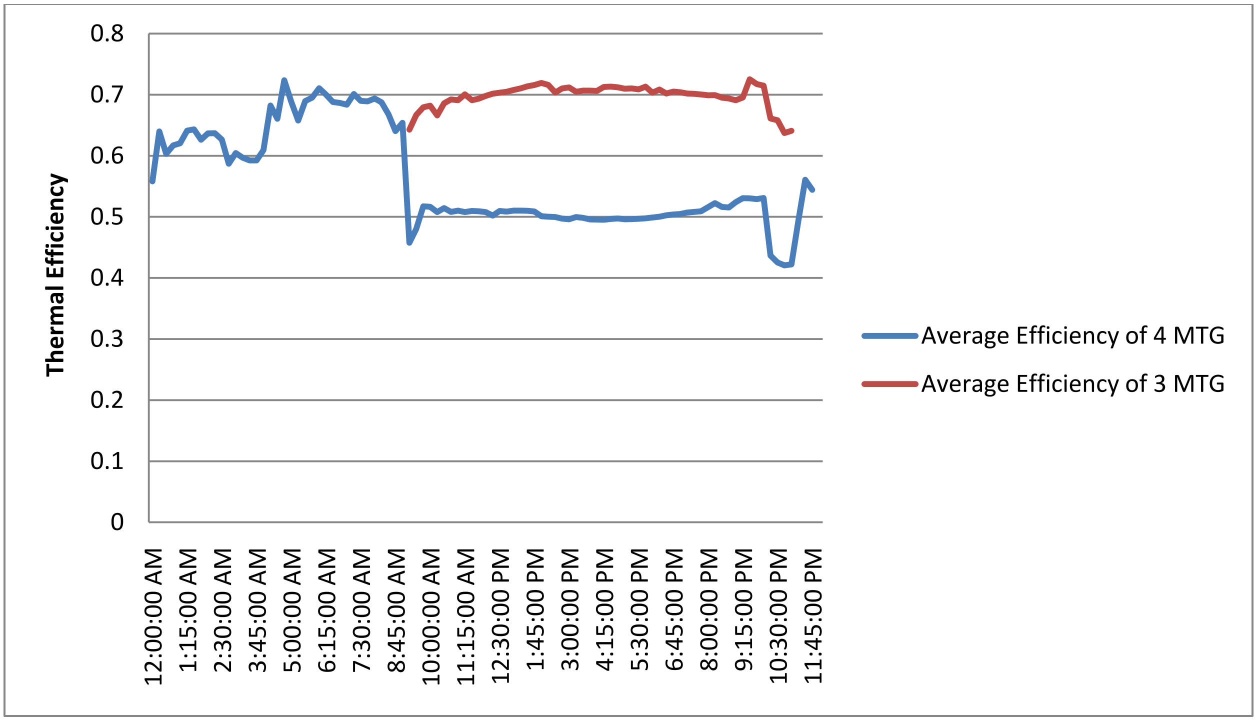


Figure 18: AQMD MTG Installation: Typical Overall Thermal Efficiency Profile: Jan - Mar 2009

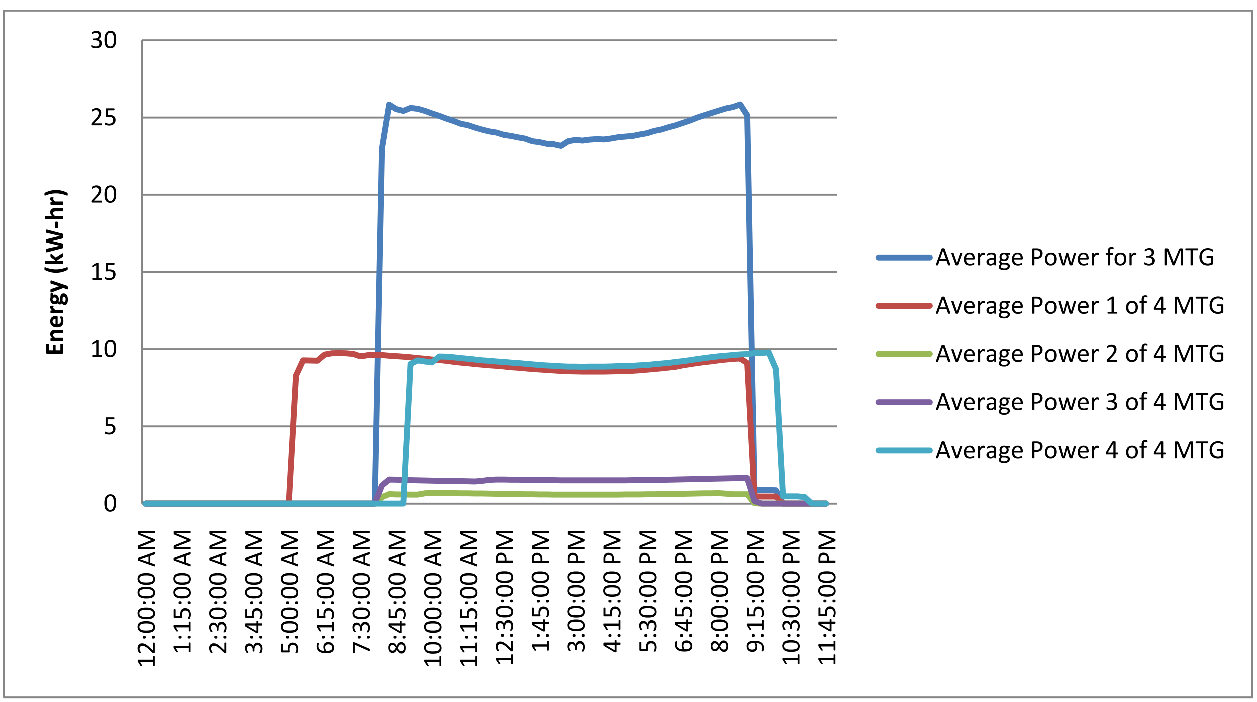


Figure 19: AQMD MTG Installation; Typical Energy Profile; April - June 2009

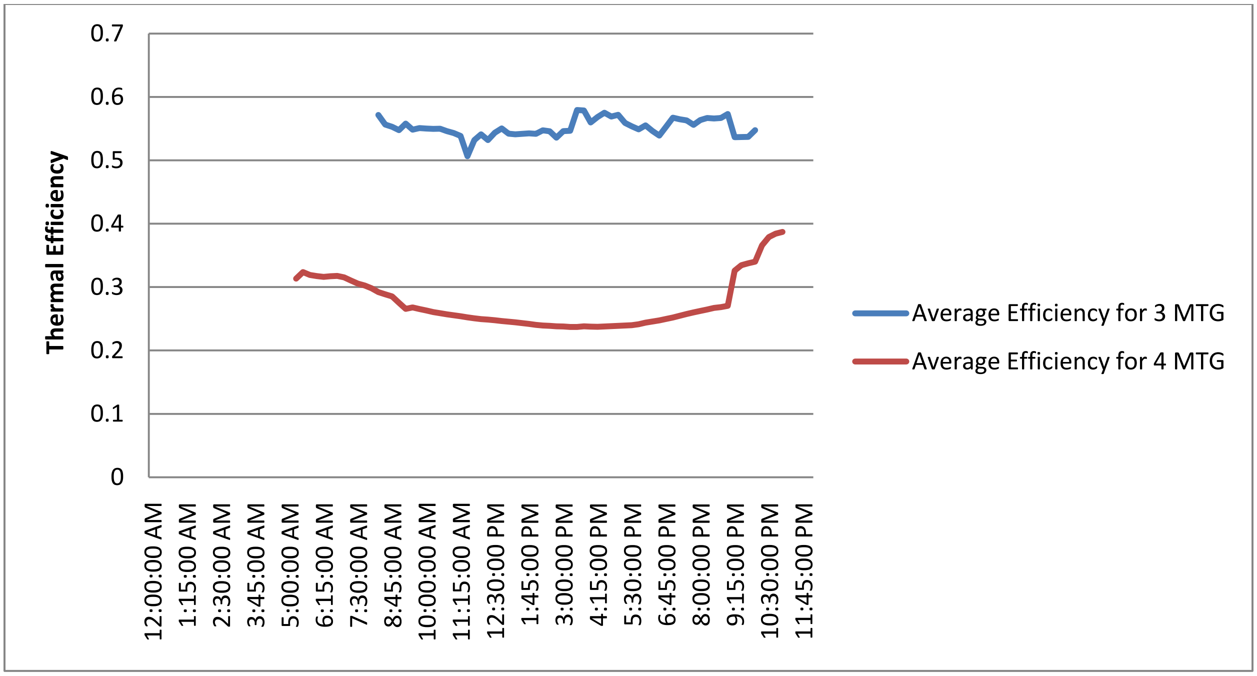


Figure 20: AQMD MTG Installation: Typical Overall Thermal Efficiency; April - June 2009

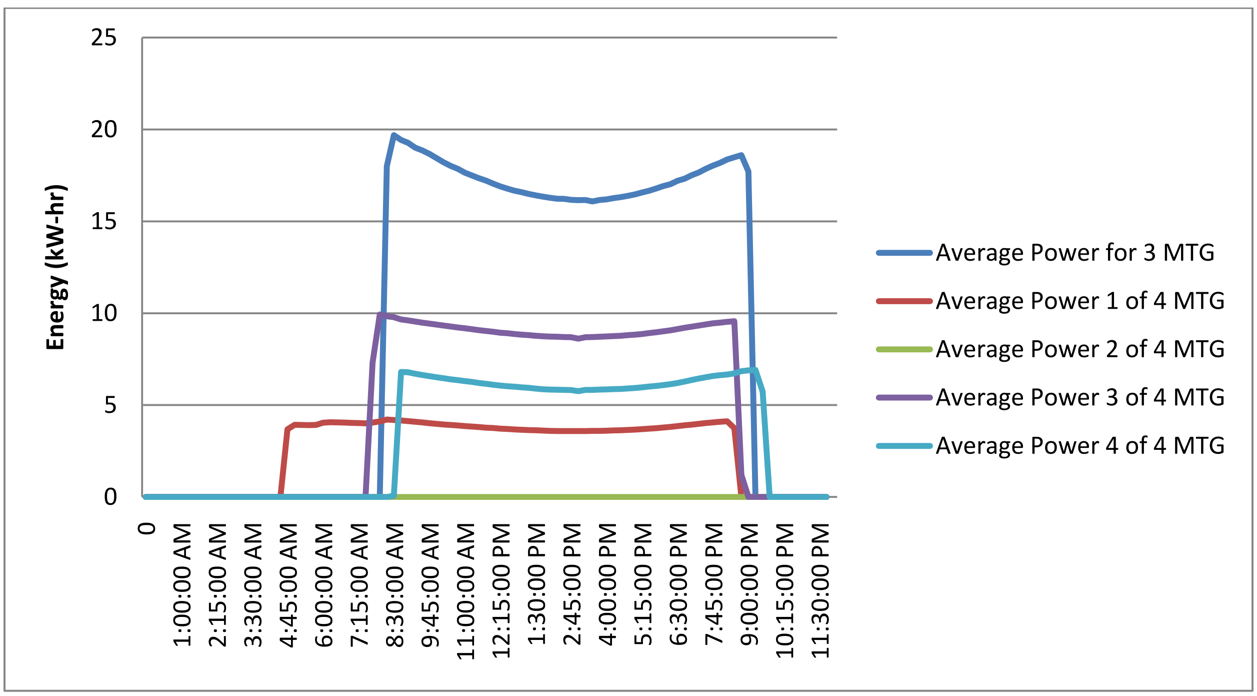


Figure 21: AQMD MTG Installation: Typical Energy Profile; July - Sept 2009

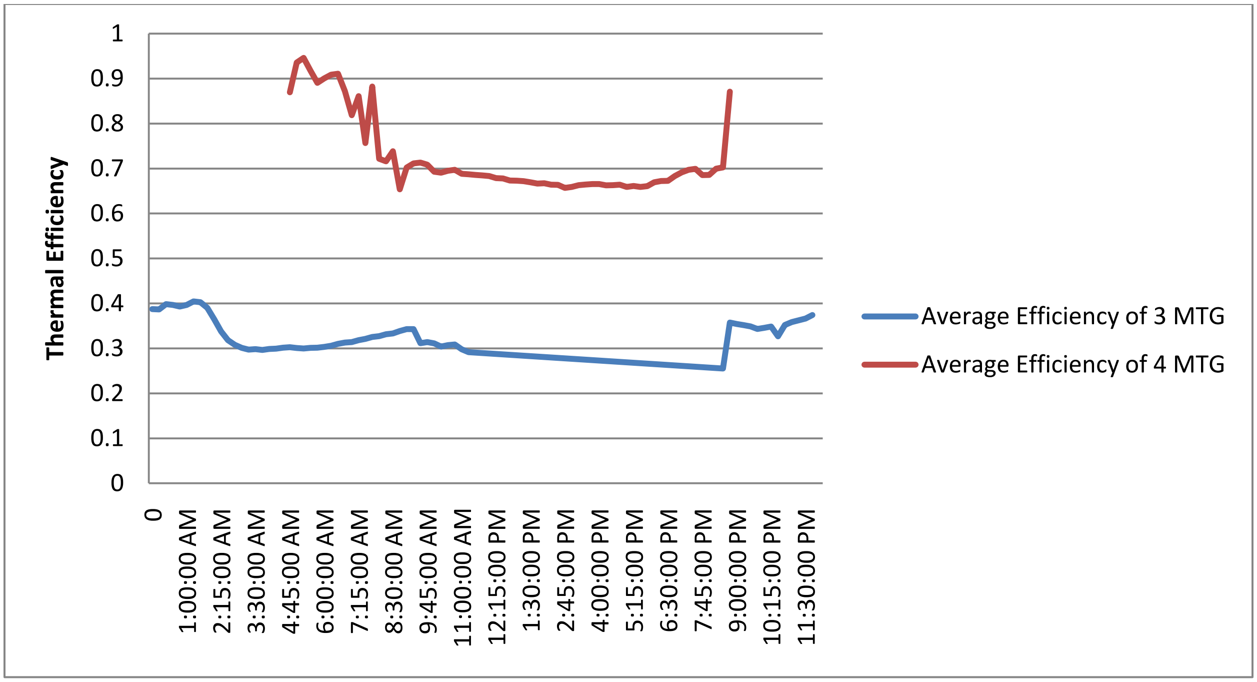


Figure 22: AQMD MTG Installation; Typical Overall Thermal Efficiency; July - Sept 2009

5.3.2. CSUN

XXXXX

5.3.3. PCC

XXX

5.3.4. UCDMC

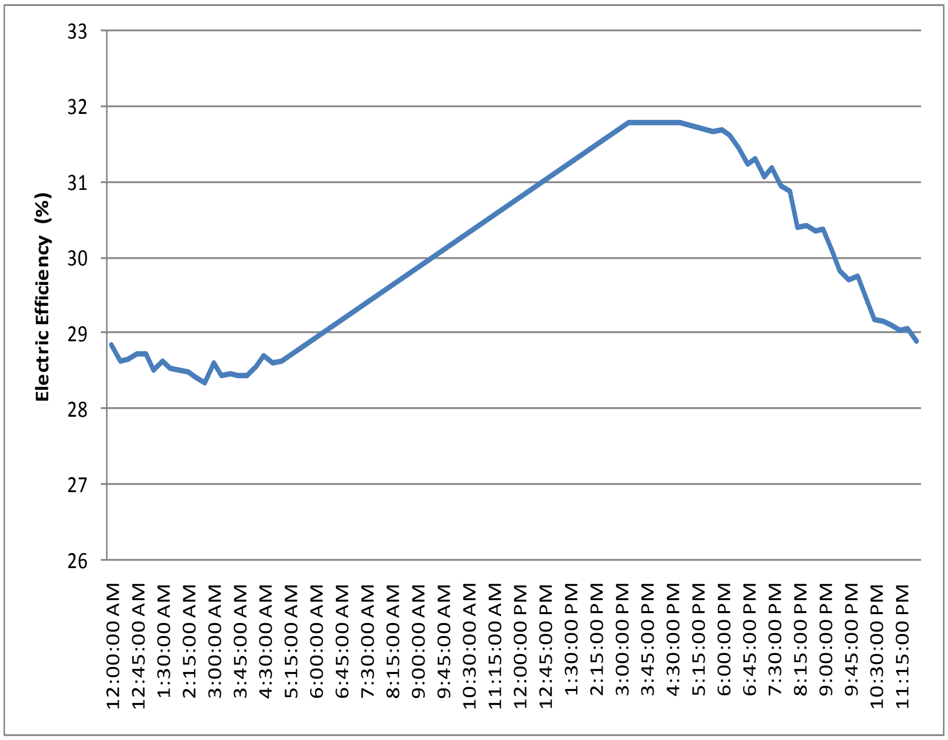


Figure 23: UCDMC Overall Electric Generation Efficiency; Oct - Dec 2008

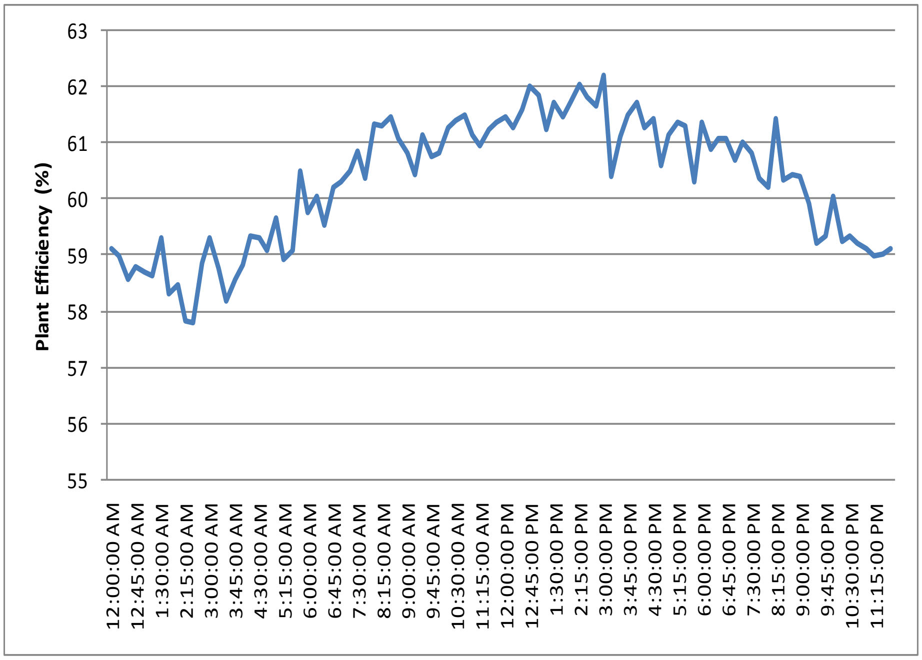


Figure 24: UCDMC: Overall Thermal Efficiency; Oct -Dec 2008

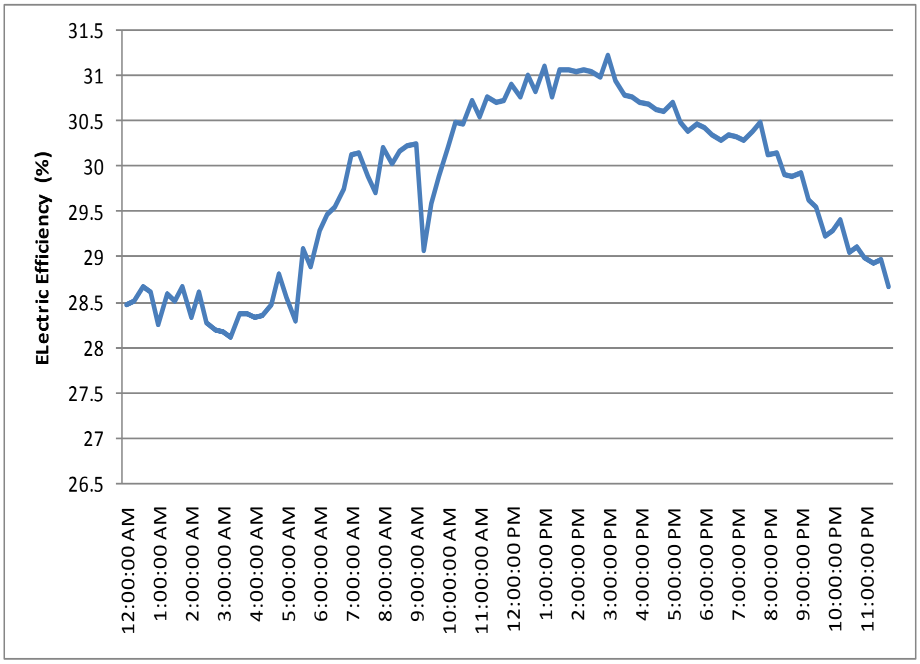


Figure 25: UCDMC: Overall Electric Generation Efficiency; Jan - Mar 2009

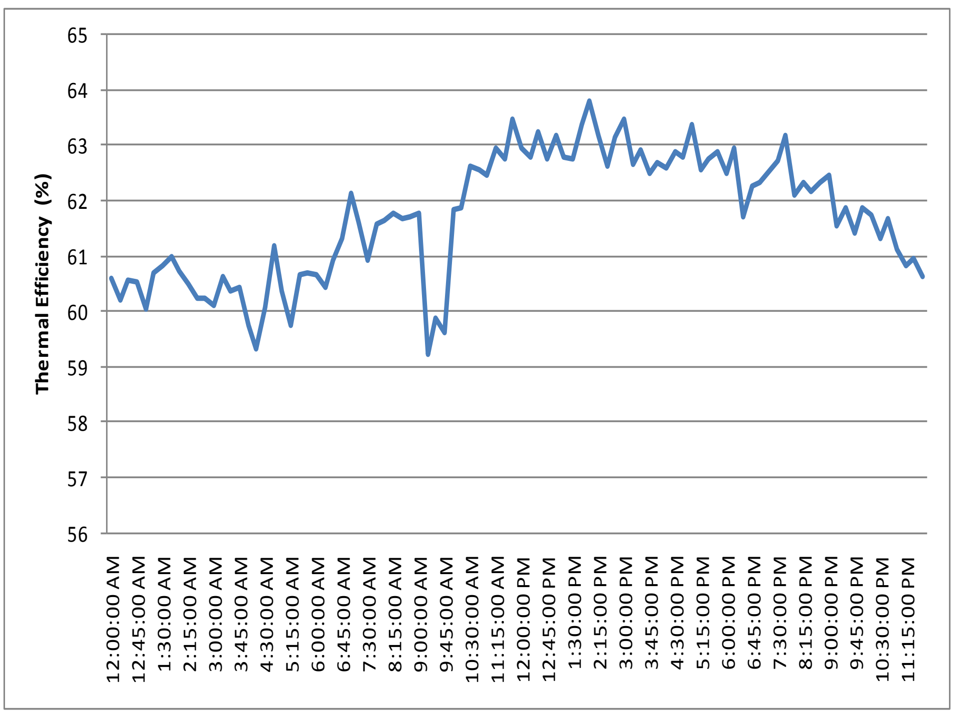


Figure 26: UCDMC Overall Thermal Efficiency; Jan - Mar 2009

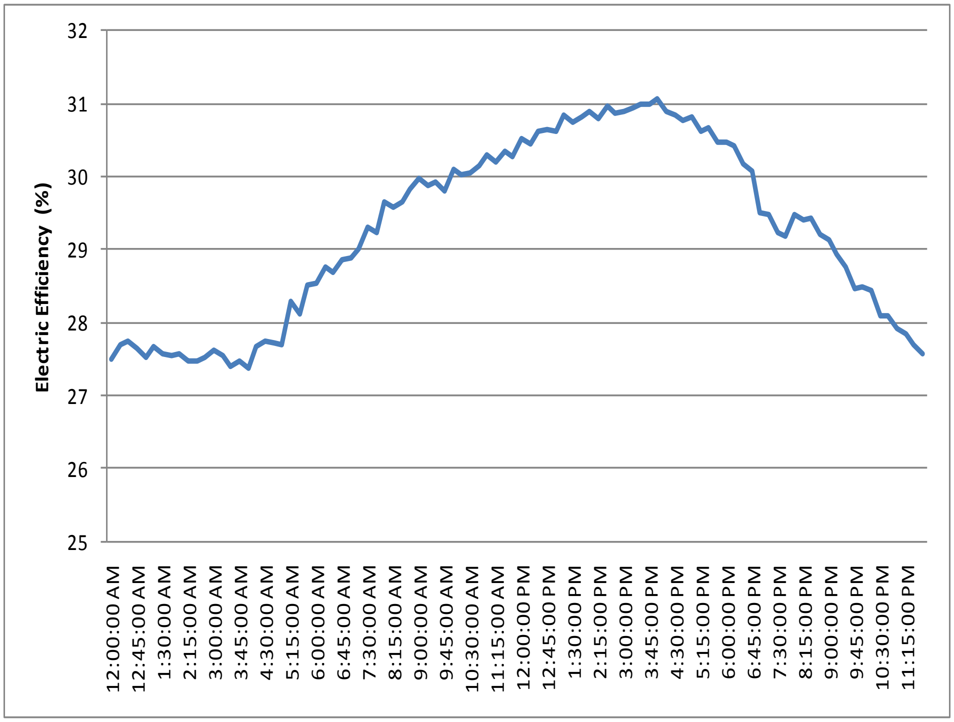


Figure 27: UCDMC Overall Electric Generation Efficiency; April - Jun 2009

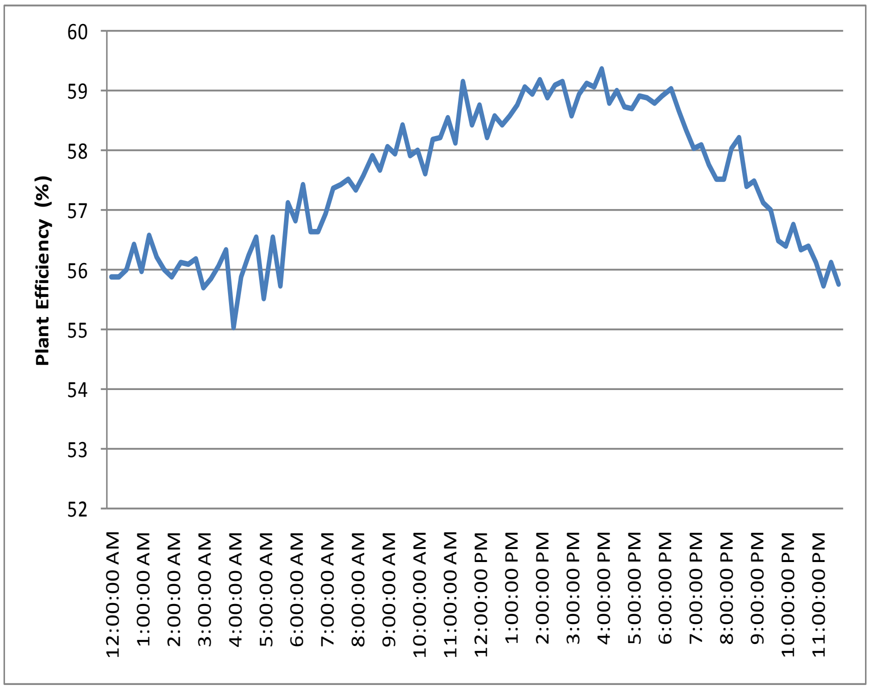


Figure 28: UCDMC Overall Thermal Efficiency; April - June 2009

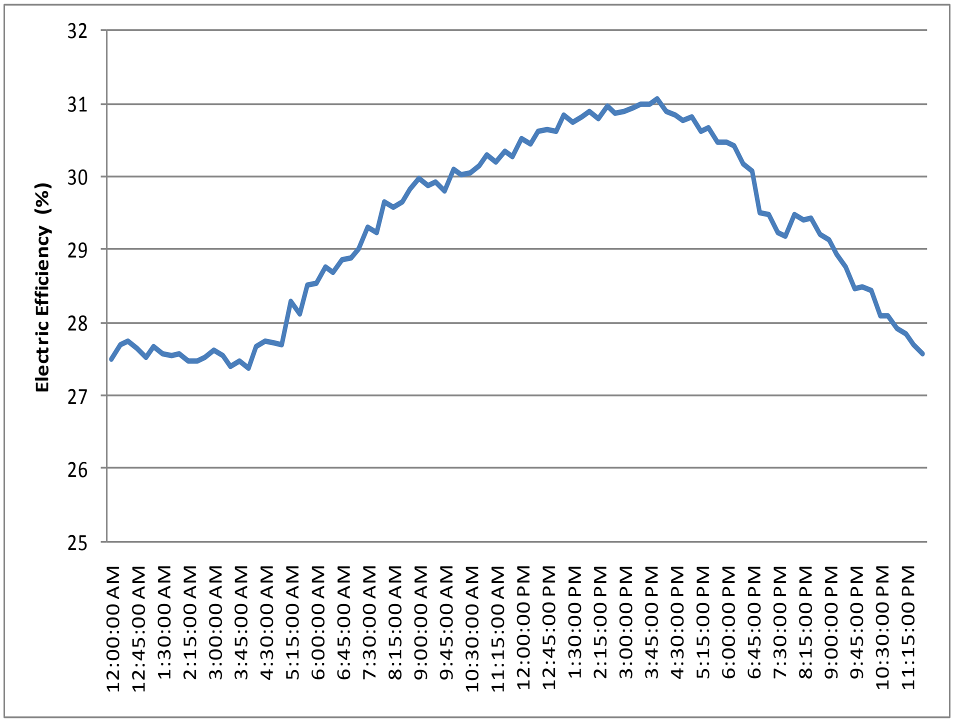


Figure 29: UCDMC Overall Electric Generation Efficiency; July - Sept 2009

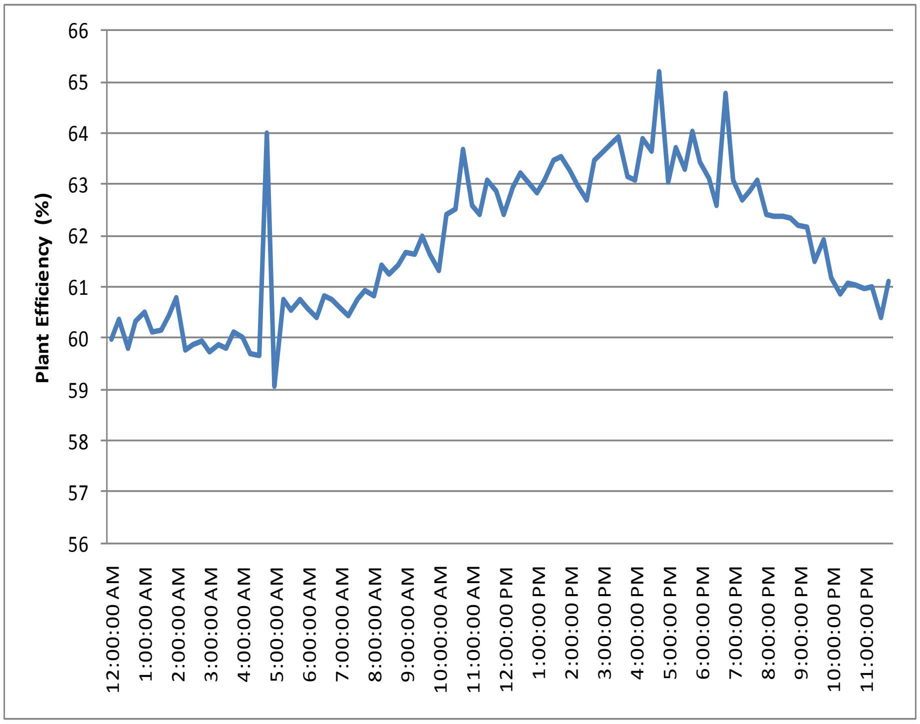


Figure 30: UCDMC: Overall Thermal Efficiency; July - Sept 2009

6.0 Relative Exposure Analysis

The effects of widespread deployment of DG/CHP systems currently has unknown impacts on the air shed. Generally, the expectations of higher overall thermal efficiency would result in reductions in the emissions of green house gases (primarily carbon dioxide). Additionally, current DG/CHP systems eligible for simplified deployment throughout California are required to meet stringent emission levels comparable to central station stationary source BACT levels but with the added caveat that 100% credit is given for all waste heat energy that is recovered and is added to the electric energy provided to establish the denominator for the emissions rate calculations (i.e. emission in "lb/MW-hr" inclusive of electric and waste energy).

An assessment of the ramifications of widespread deployment of DG/CHP is addressed in this task. The evaluation undertaken herein is at two distinct and diverse scales. The first assessment evaluates the impacts on an air shed level (e.g. the South Coast Air Basin) relative to particulate and ozone level while the second evaluates the effect of the emissions on the near field adjacent to the DG system ambient air quality relative to standard for criteria pollutants.

6.1. Air Shed Impacts Modeling

6.1.1. Summary

This report analyzes the potential impacts of using combined cooling, heating and power (CCHP) applications to supply electrical and thermal needs to food retail stores in the South Coast Air Basin of California (SoCAB). The use of CCHP would displace power supply from the grid, that otherwise would be required for the food retail sector.

Based on estimates by the California Energy Commission, the food retail industry consumed 4401 GWh in the year 2007, 3.6% of total consumption in the basin. This level of consumption is equivalent to an average power capacity of 500 MW. Hence, the use of CCHP in the SoCAB could enable the removal of one average-sized power plant.

6.1.2. Spatial Distribution of Distributed Generation for Retail Stores

Figure 31 and Figure 32 depict the spatial information that is available to allocate on-site distributed power generation for food retail stores. The image corresponds to a subset of Geographical Information Systems (GIS) land use data for the South Coast Air Basin of California (SoCAB). GIS land use data includes spatial information of four different categories of retail activities:

- Regional shopping centers: this category includes large retail malls such as the South Coast Plaza, Fashion Island and the Irvine Spectrum. Typically, these areas do not include large food retail stores.
- Retail centers: this category includes a mix of food retail stores (e.g. Albertson's, Vons) with general retail stores that also serve food products (e.g. Target, Costco). In addition, these areas include restaurants.
- Modern strip development: these areas include mostly restaurants, bars and convenience stores.

- Older strip development: as in modern strip development, these areas include mostly restaurants, bars and convenience stores.

The purpose of this study is to analyze the potential air quality impact of using distributed generation (DG) in large food retail stores. Retail centers category (category 2) is the GIS land use type that includes most food retail stores. Consequently, that category is used to spatially allocate DG installations in the SoCAB. Figure 33(a) presents the spatial distribution of retail center area in the SoCAB. There is a high percentage of area (~1%) in the retail store category north of Riverside (in the Riverside County) and south of Anaheim (in the Orange County), whereas as in central Los Angeles the area designated for retail stores is less than 0.2%.

Regarding energy use for food refrigeration, one would expect to find the peak demand around areas with the highest population density, such as central Los Angeles. However, GIS land use data does not correlate directly with population density, shown in Figure 33(b). GIS land use data only provides information on the ground level area of the retail store. It does not include information of whether stores include multiple floors and it does not provide information on sales volumes, which can affect the total energy load required for food retail stores. As a result, using information in Figure 33(a) alone as a spatial surrogate for distribution of DG would bias DG deployment towards Riverside. To correct this bias, the spatial distribution of DG is the normalized product of retail store area multiplied by the population density. The resulting spatial distribution is presented in Figure 33(c).

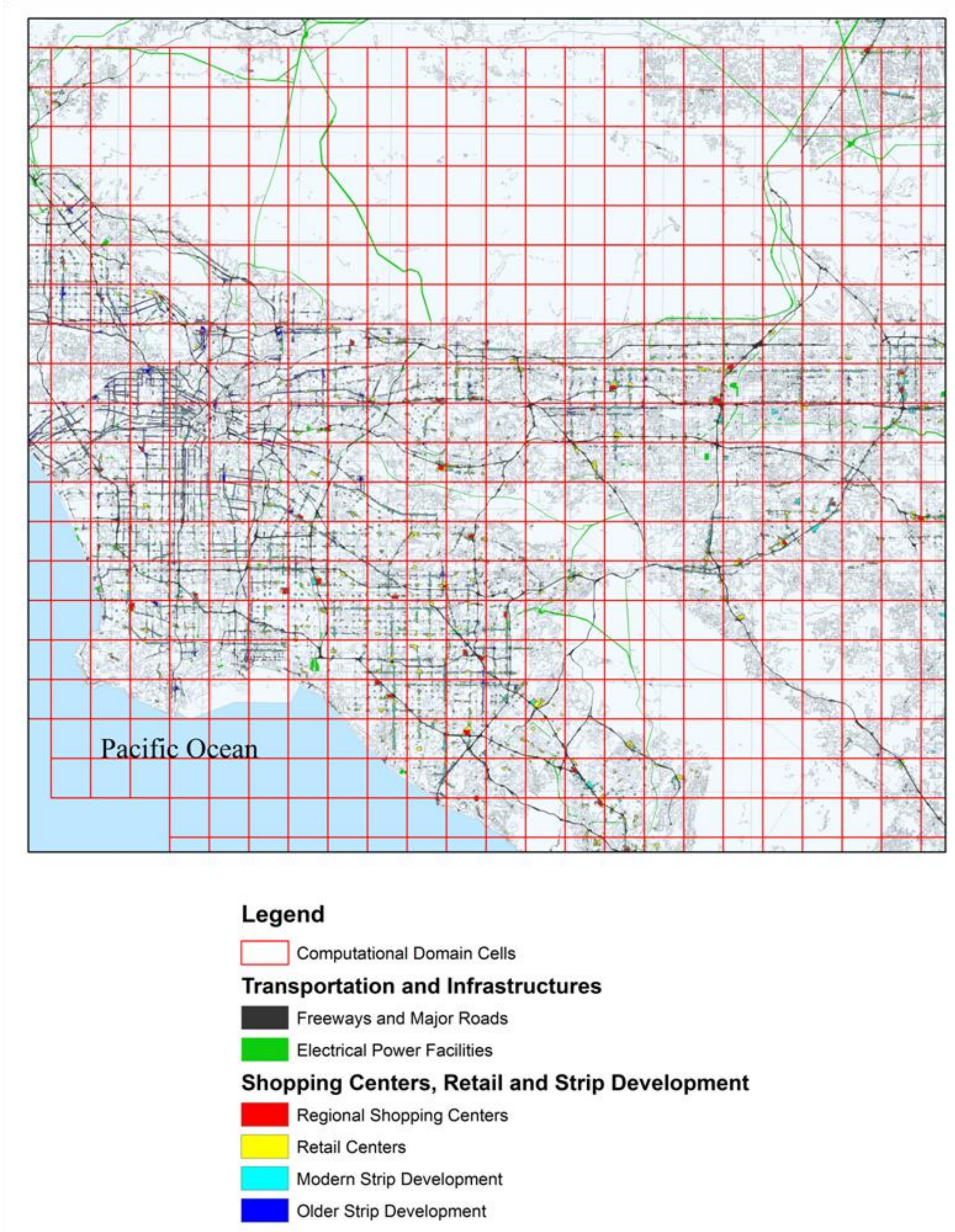


Figure 31: GIS land use data of spatial distribution of retail centers in the South Coast Air Basin.

Figure 32: Insert of Figure 31 showing GIS land use data of spatial distribution of retail centers in around the Newport Beach area.

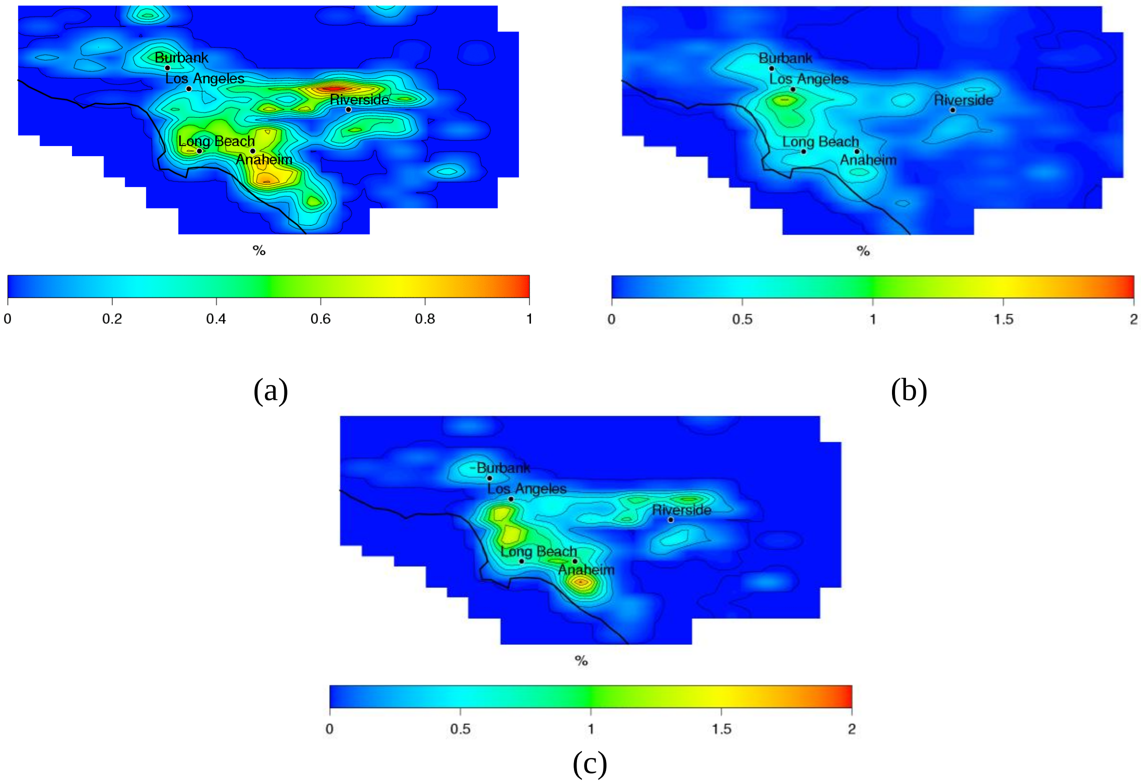


Figure 33: Options for spatial distribution of distributed generators for food retail stores: (a) retail stores area spatial distribution, (b) population distribution in 2010, (c) spatial distribution of the normalized product between population density and retail store area density

6.1.3. Energy Displacement Due to Combined Cooling heating and Power

Electricity use for food retail contributed 3.2% and 3.6% to total electricity consumption in 2006 and 2007, respectively (Table 4). Electricity use in food retail increased from 2006 to 2007 in all counties, and in the long term, electricity use in general is expected to grow at an annual rate of 1.5%. Consumption data for the year 2008 have not been released yet, but it is expected that the current crisis impacted industrial and commercial activity, and total electricity consumption as a result. Consequently, no reliable short term projections can be made before new data becomes available.

Table 5 presents the contribution of electricity end use within food retail operations. The data presented here correspond to average electricity use in North American food retail operations. Other references suggest only slight variations of the electricity use distribution in the food retail sector in Italy and the UK (Arteconi et al. 2009, Sugiartha et al. 2009). The total contribution of refrigeration loads adds up to 55% of the total electricity needs in a food retail store. Due to thermodynamic and economic limitations, CCHP is unlikely to be used to offset electricity use for low temperature refrigeration (refrigeration under 20 °F, which includes refrigeration for all frozen goods). Conversely, electrical load for high temperature refrigeration

– refrigeration between 20 °F and 50 °F, and subcooling refrigeration loads – and air conditioning could be partially met by CCHP.

Table 4 Electricity consumption in food retail and related activities by county (from the energy consumption data management system, California Energy Commission)

County	Electricity Consumption - Year 2006		
	Food retail* (Million kWh)	**Total** (Million kWh)	**Food retail contribution** (%)
Los Angeles	2279	70662	3.2
Orange	704	21145	3.3
Riverside	422	14840	2.8
San Bernardino	453	14594	3.1
Total	3858	121241	3.2

County	Electricity Consumption - Year 2007		
	Food retail (Million kWh)	**Total** (Million kWh)	**Food retail contribution** (%)
Los Angeles	2519	69666	3.6
Orange	920	21905	4.2
Riverside	476	14645	3.2
San Bernardino	487	15505	3.1
Total	4401	121720	3.6

* Food retail encompasses grocery, food and beverages stores, categories included in the North American Industrial Classification System (NAICS).

Table 5: Distribution of electricity needs by end use in food retail stores (ASHRAE, 2008)

End use	**%**
Refrigeration needs:	
Low temperature refrigeration [a]	12
High temperature refrigeration [b]	38
Heating, ventilating and air conditioning	5
Other needs:	
Lighting	38
Food preparation	7

[a] Low Temperature Refrigeration: refrigeration under 20 ^{o}F
[b] High Temperature Refrigeration: refrigeration above 20 ^{o}F and under 50 ^{o}F, which includes subcooling refrigeration loads

Figure 34 through Figure 37 show four possible CCHP configurations as an alternative to conventional "grid connected" electricity use in food retail stores wherein all the electricity and thermal loads are supplied by electricity from the grid. The four CCHP cases assume that the CCHP is self-sufficient, and does not require additional electricity from the grid. The four cases presented in figures below are the following:

1. Internal Combustion Engine (ICE) prime mover; HVAC load priority for CCHP(Figure 34): the CCHP system provides all the electrical needs, and the excess heat is used in an absorption chiller to provide the cooling needs for HVAC. Since HVAC loads are a small portion of the total cooling load – 0.14 $MW_{cooling}$ per MW of total electricity used from the grid – there remains excess heat that is used to meet a fraction of high temperature refrigeration: 0.54 $MW_{cooling}$ out of 0.84 $MW_{cooling}$. As a result, additional 0.29 MW of cooling from electricity is required to balance all thermal loads. Overall, the electric power of the CCHP system required to offset 1 MW of electric power used from the grid is 0.70 MW.
2. ICE prime mover; High Temperature Refrigeration load priority for CCHP (Figure 35): the CCHP system provides all the electrical needs, and the excess heat is used in an absorption chiller to provide the cooling needs for high temperature (HT) refrigeration. Since HT refrigeration loads are a large portion of the total cooling load – 0.84 $MW_{cooling}$ per MW of total electricity used from the grid – the excess heat from the CCHP system can only meet a fraction of the high temperature refrigeration load: 0.67 $MW_{cooling}$ out of 0.84 $MW_{cooling}$. As a result, additional 0.30 MW of cooling from electricity is required to balance all thermal loads. Overall, the electric power of the CCHP system required to offset 1 MW of electric power used from the grid is 0.70 MW, the same as in case (1).
3. Molten Carbonate Fuel Cell (MCFC) prime mover; HVAC load priority for CCHP (Figure 36): the CCHP system provides all the electrical needs, and the excess heat is used in an absorption chiller to provide the cooling needs for HVAC. As in case (1), there remains excess heat that is used to meet a fraction of high temperature refrigeration: 0.19 $MW_{cooling}$ out of 0.84 $MW_{cooling}$. As a result, additional 0.64 MW of cooling from electricity is required to balance all thermal loads. Overall, the electric power of the CCHP system required to offset 1 MW of electric power used from the grid is 0.85 MW. This system size is larger than in the case of CCHP with ICE, because of the higher efficiency, and hence lower excess heat, of the MCFC system.
4. MCFC prime mover; High Temperature Refrigeration load priority for CCHP (Figure 37): the CCHP system provides all the electrical needs, and the excess heat is used in an absorption chiller to provide the cooling needs for high temperature (HT) refrigeration. Since HT refrigeration loads are a large portion of the total cooling load – 0.84 $MW_{cooling}$ per MW of total electricity used from the grid – the excess heat from the CCHP system can only meet a fraction of the high temperature refrigeration load: 0.32 $MW_{cooling}$ out of 0.84 $MW_{cooling}$. As a result, additional 0.65 MW of cooling from electricity is required to balance all thermal loads. Overall, the electric power of the CCHP system required to offset 1 MW of electric power used from the grid is 0.85 MW, the same as in case (3).

The assumptions regarding efficiency and coefficient of performance of the different equipment used in the analysis are presented in Table 6.

Table 6: Parameters for the electrical and cooling systems considered in the study

Parameter		Value
Low Temperature Electric Chiller COP	COP_{LTcool}	1.60
High Temperature Electric Chiller COP	COP_{HTcool}	2.20
HAVC Electric Chiller COP	COP_{HVAC}	2.80
High Temperature Absorption Chiller COP	$COP_{absChill, HT}$	0.67
HAVC Absorption Chiller COP	$COP_{absChill, HVAC}$	0.75
ICE electrical efficiency	$\eta_{ICE,elec}$	0.35
ICE total efficiency	$\eta_{ICE,total}$	0.85
MCFC electrical efficiency	$\eta_{MFCF,elec}$	0.48
MCFC total efficiency	$\eta_{MFCF,total}$	0.75

Based on the analysis of the four cases presented above, the total capacity of CCHP units that would be required to offset electricity used from the grid depends on the prime mover and the primary use of the excess heat. Utilization of the excess heat in CCHP reduces the total capacity needed to provide for electrical and thermal loads. In the cases of ICE systems, the total electricity production by CCHP required to offset the baseline electricity of 4401 GWh/year would be 3073-3093 GWh/year. Assuming a constant power consumption throughout the year, the average capacity of CCHP installations would be 351-353 MW, 30% lower than the average baseline capacity required for food retail stores in the year 2007 (502 MW). For the cases with MCFC systems, the reduction in capacity is less pronounced than in the ICE cases, due to the higher energy efficiency of the MCFC systems. The reduction in electricity production would be 14-15%, requiring an average installed capacity of 427-430 MW. Assuming that an average food retail store would require a 150 $kW_{electric}$ system, meeting the electricity and cooling demand would require 2338-2354 ICE units, or 2843-2867 MCFC units.

Table 7: DG/CHP Application in food retail stores in the South Coast Air Basin of California

Cases		Electricity generation (GWh/year)	Average power (MW)	Number of 150 kW installations
	As Built Grid Connected case (2007)	4401	502	N/A
Case 1	ICE meeting HVAC load	3073	351	2338
Case 2	ICE meeting HT refrigeration	3093	353	2354
Case 3	MCFC meeting HVAC load	3736	427	2843
Case 4	MCFC meeting HT refrigeration	3767	430	2867

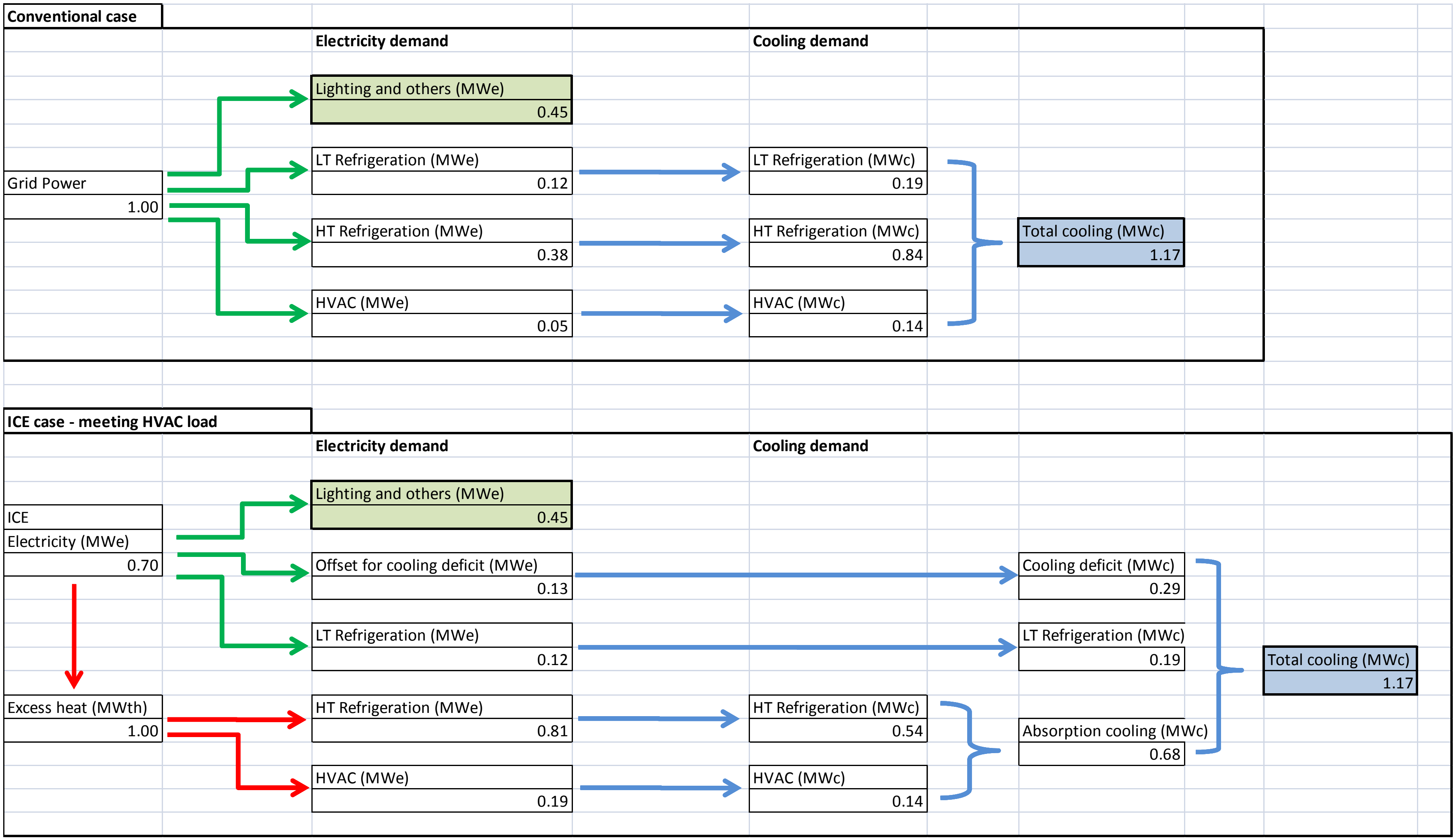


Figure 34: Energy balance in food retail store; ICE prime mover; HVAC Priority. .

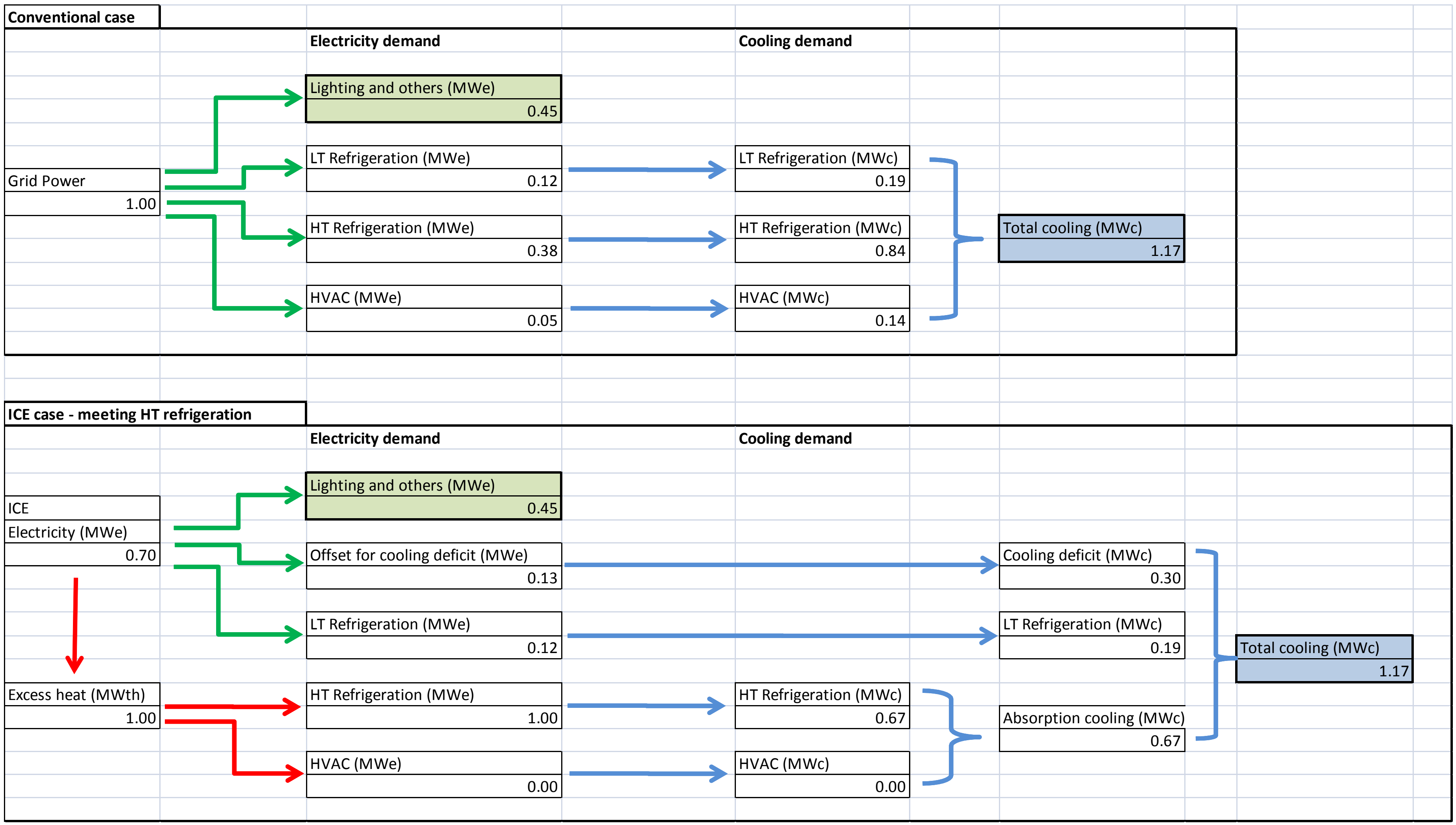


Figure 35: Energy balance in food retail store. ICE Prime Mover, High Temperature Refrigeration Priority: Additional cooling produced from electricity is needed to meet total high temperature refrigeration and HVAC loads.

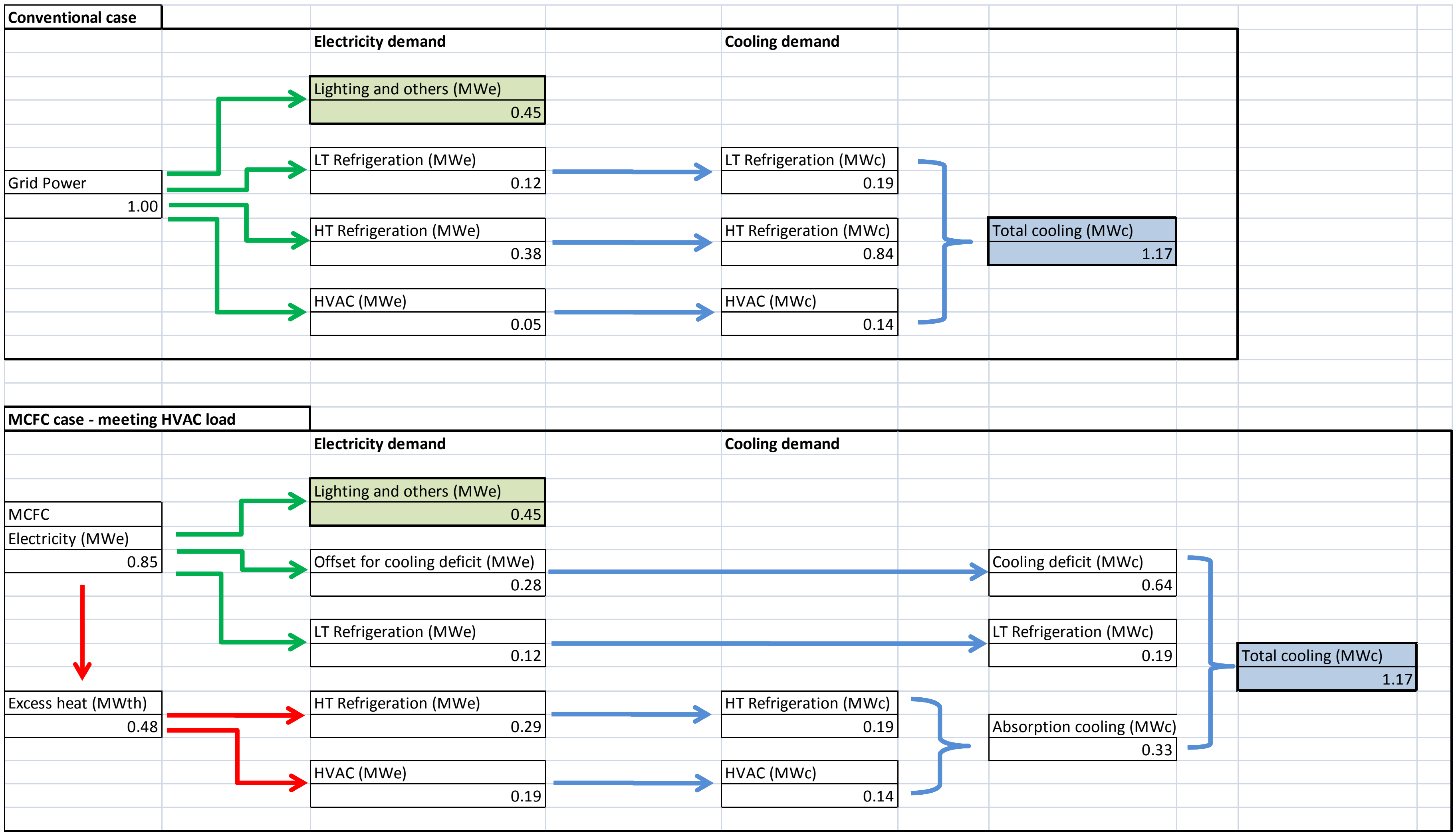


Figure 36: Energy balance in food retail store. MCFC Prime Mover; HVAC Priority

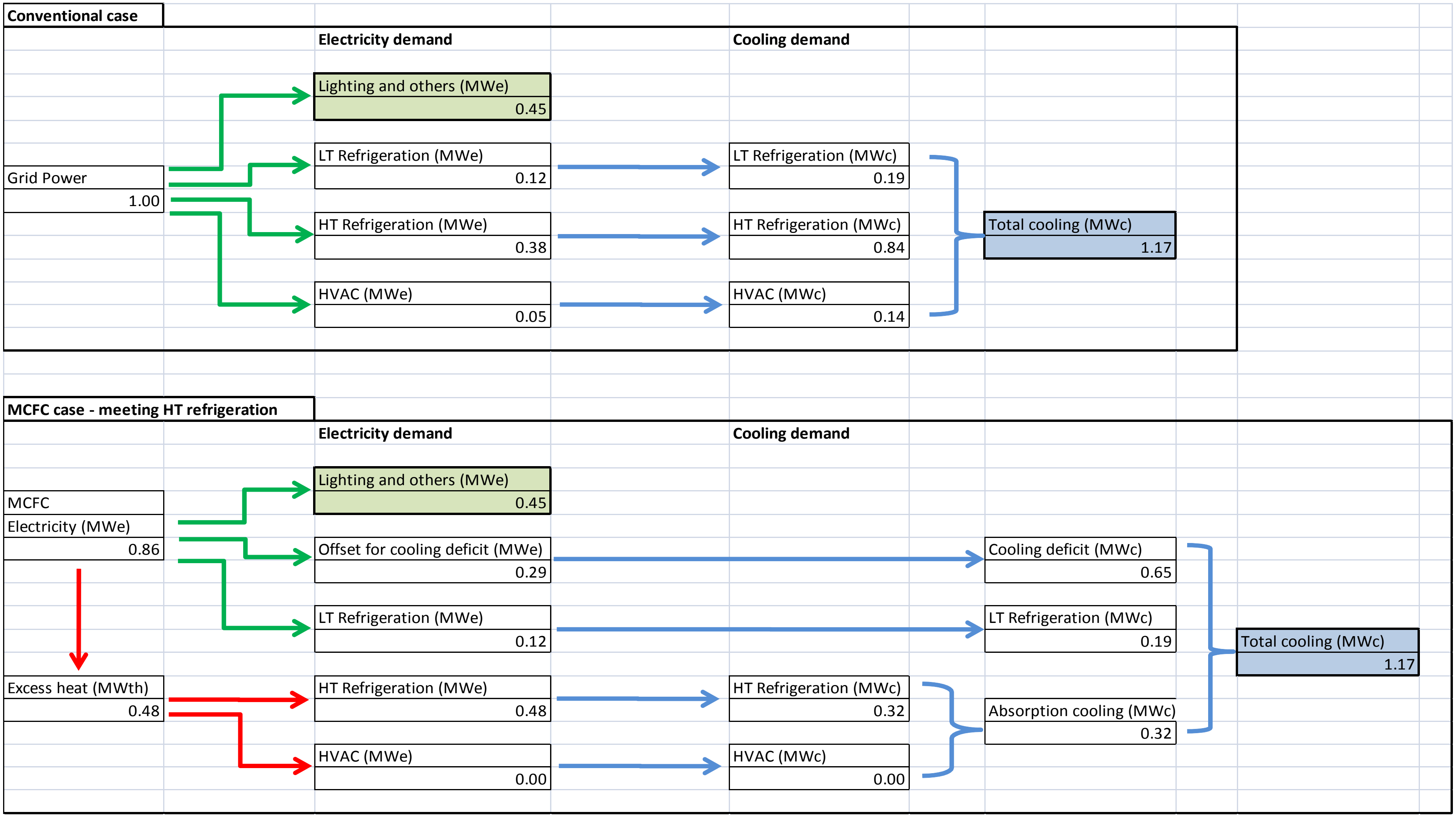


Figure 37: Energy balance in food retail store. MCFC Prime Mover; High Temperature Refrigeration Priority

Additional cooling produced from electricity is needed to meet total high temperature refrigeration and HVAC loads.

6.1.4. Impact of CCHP in pollutant emissions

This section evaluates the emission changes due to implementation of CCHP systems to offset electricity use from the grid. The emission factors used in the analysis are presented in Table 8. Emissions from MCFC systems are lower than the corresponding 2007 ARB emission standards for distributed generation installations. In contrast, emissions from ICE systems do not comply with current BACT standards unless they include an after-treatment control measure. For electricity generation alone, ICE systems require a significant reduction of emissions to comply with the BACT standards. The use of CCHP in ICE units allows for emission credits that equals a thermal load unit with an electric load unit. In the case of ICE CCHP systems, the thermal load utilized from the ICE system is 1 $MW_{thermal}$ per 0.7 $MW_{electric}$ (1.43 $MW_{thermal}/MW_{electric}$). The emission credits results in an effective increase in permitted emissions of 143%.

Table 8: Emission factors for MCFC and ICE installations

Pollutant	EF_{MCFC}[a] (lbs/MWh_e)	EF_{ICE} (lbs/MWh_e)	$EF_{ICE\text{-}BACT}$ (lbs/MWh_e)	$EF_{ICE\text{-}CHP\text{-}BACT}$ (lbs/MWh_e)[e]
NO_X	0.050	0.310[b]	0.070	0.170
CO	0.040	1.500[b]	0.200	0.486
VOC	0.005	0.460[b]	0.100	0.243
PM_{10}		0.120[c]	0.013[d]	0.032
SO_2		0.007[b]	0.024[d]	0.007

[a] Table 7.3, Emissions for 250kW MCFC estimated for 2010, DER Emissions Survey and Technology Characterization, E2I, 2005
[b] Table 6-5, Emissions for 100 kW system estimated for the year 2010, DER Emissions Survey and Technology Characterization, E2I, 2005
[c] Table 6-4, lower limit for PM_{10} emissions, DER Emissions Survey and Technology Characterization, E2I, 2005
[d] Based on Combined Cycle Power plant BACT
[e] Includes CHP credits. Expressed as Minimum between EF_{ICE} and $EF_{ICE\text{-}BACT}*(1+W_{elec}/W_{th})$

Table 9 presents the resulting basin-wide emissions from the deployment of CCHP installations. Emissions from MCFC installations are considerably lower than in the case with ICE, even though the total installed capacity in the MCFC case is 22% larger than the required capacity in the ICE case. Compared to the emissions from a power plant located in Huntington Beach that produce comparable power required by the conventional case, the MCFC option would result in net reduction in pollutant emissions. In contrast, the ICE option would lead to net increases in emissions. It is important to note that the emission changes due to CCHP deployment are of the order of less than 0.1% of the total emission in the basin from all sources.

Table 9: Total emissions from deployment of CCHP installations in food retail stores.

Pollutant	Distributed generation with CCHP: MCFC meeting HT refrigeration	Distributed generation with CCHP: ICE meeting HT refrigeration	Central power plant[a]: AES Huntington Beach	2005 Emissions Inventory[a]
Capacity (MW)	430	353	888[b]	
Pollutant Emissions (tons/day)				
NO_X	0.23	0.65	0.32	746
CO	0.19	1.87	1.26	4111
VOC	0.02	0.94	0.03	1262
PM_{10}	-	0.12	0.11	605
SO_2	-	0.03	0.02	88

[a] Emissions extracted from the 2005 inventory provided by the South Coast Air Quality Management District
[b] Nameplate capacity

6.1.5. Baseline Air Quality

The gas-phase chemical mechanism used in the present simulations is the Caltech Atmospheric Chemical Mechanism (CACM, see Griffin et al. 2002a). The CACM is based on the work of Stockwell et al. 1997; Jenkin et al. 1997; and Carter 2000. It includes ozone (O3) chemistry and a state-of-the-art mechanism of the gas phase precursors of secondary organic aerosol (SOA). The full mechanism consists of 361 chemical reactions and 191 gas-phase species, which describe a comprehensive treatment of VOCs oxidation. The model includes 37 size-resolved aerosol-phase species, in 8 different size bins ranging from 0.04 to 10 microns.

The grid used by the UCI-CIT model encompasses Orange County and part of Los Angeles, Ventura, San Bernardino, and Riverside counties (Figure 38). The grid consists of cells with an area of 25 km2. Additionally the vertical resolution is described through five vertical layers with the following dimensions from ground level up: (1) 0 m–39 m, (2) 39 m–154 m, (3) 154 m–308 m, (4) 308 m–671 m, and (5) 671 m–1100 m.

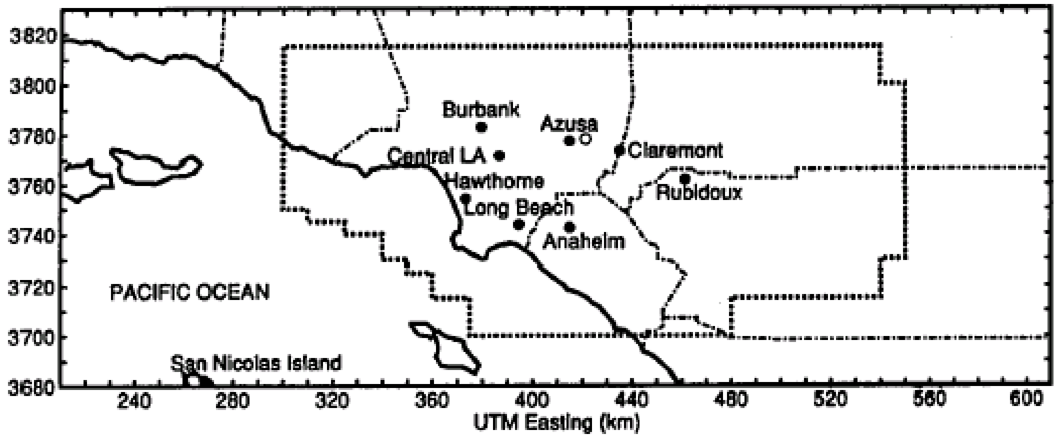


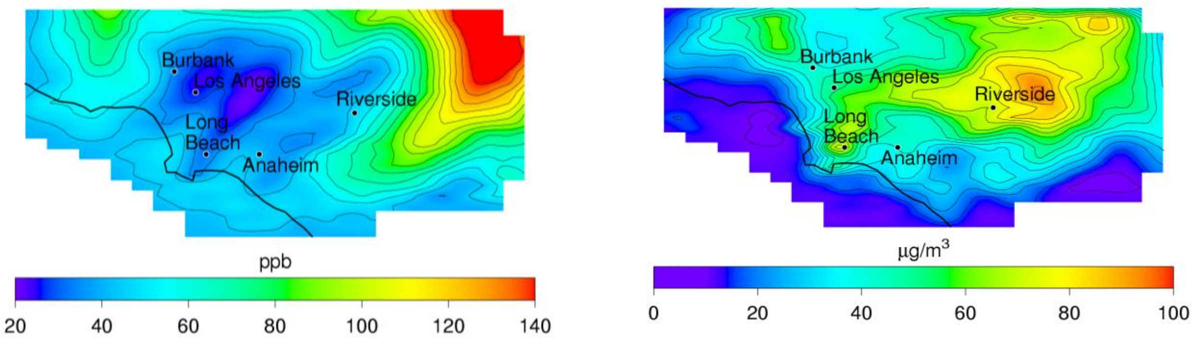
Figure 38: UCI-CIT Airshed modeling domain of the South Coast Air Basin of California

Meteorological conditions were obtained during the Southern California Air Quality Study (SCAQS), which was a comprehensive campaign of atmospheric measurements that took place in the SoCAB during August 27–29, 1987. The study collected an extensive set of meteorological and air quality data that has been used widely to validate air quality models (Meng et al. 1998; Griffin et al. 2002a; Griffin et al. 2002b; Moya et al. 2002). Zeldin et al. (1990) found that August 28, 1987, is representative of the meteorological conditions in the SoCAB, which makes it suitable for modeling. In addition, the August 27–28, 1987, episode is statistically within the top 10% of severe ozone-forming meteorological conditions. Hence, meteorological conditions for August 27-29 are used here as the basis to evaluate air quality impacts of DG.

The SCAQS episode in August 27–29, 1987 was characterized by a weak onshore pressure gradient and warming temperatures aloft. The wind flow was characterized by a sea breeze during the day and a weak land-mountain breeze at night. The presence of a well-defined diurnal inversion layer at the top of neutral and unstable layers near the surface, along with a slightly stable nocturnal boundary layer, facilitated the accumulation of pollutants over the SoCAB, which lead to a high ozone concentration occurrence.

The emissions were obtained from the South Coast Air Quality Management District (AQMD). The emissions correspond to a summer episode in 2005 that was included in the 2007 Air Quality Management Plan developed by the AQMD to demonstrate attainment of the 8-hour ozone standard. Total basin-wide emissions for this episode are presented in Table 9.

The resulting peak 8-hour ozone and 24-hour $PM_{2.5}$ average concentrations are shown in Figure 39. Ozone concentration peaks downwind from Los Angeles, on the northeastern corner of the domain. Maximum $PM_{2.5}$ concentrations occur near Riverside, where the ammonia emitted from agricultural and dairy activities react with nitric acid formed from NO_X emitted upwind. The result is the formation of secondary ammonium nitrate particles. A secondary $PM_{2.5}$ peak occurs near the port of Long Beach, where there are high emissions of particles and SO_X.



(a) (b)

Figure 39: Baseline pollutant concentrations resulting from summer emissions for the year 2005: (a) peak 8-hour ozone average, (b) 24-hour average $PM_{2.5}$ concentrations

6.1.6. Air Quality Impacts of DG in Food Retail Stores

The air quality impacts of CCHP deployment in food retail stores are quantified using two scenarios:

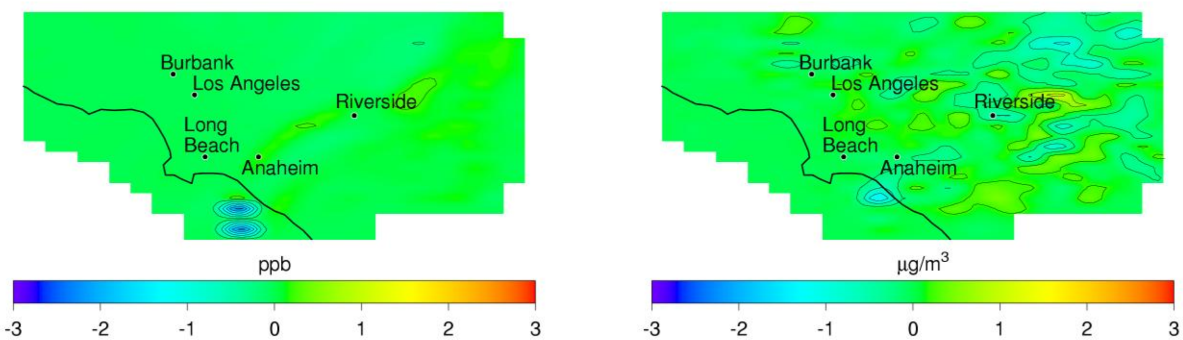
1. CCHP by ICE meeting high temperature refrigeration and shut down of the AES Huntington Beach plant
2. CCHP by MCFC meeting high temperature refrigeration and shut down of the AES Huntington Beach plant

The net emission changes of the two scenarios are calculated subtracting the AES Huntington Beach power plant emissions from the emissions of the CCHP installations. Relative to total basin-wide emissions for 2005, the emission changes due to the two scenarios are less than 0.1% (see Table 10). However, the reduction of emissions produced by the power plant shutdown is concentrated in one point, whereas the increase in emissions from CCHP installations is spread throughout a large area of the domain. As a result, the changes in pollutant concentrations are still noticeable.

Table 10: Net changes in emissions due to two CCHP scenarios, in percentage (%) with respect to total basin-wide emissions in the South Coast Basin of California in the year 2005

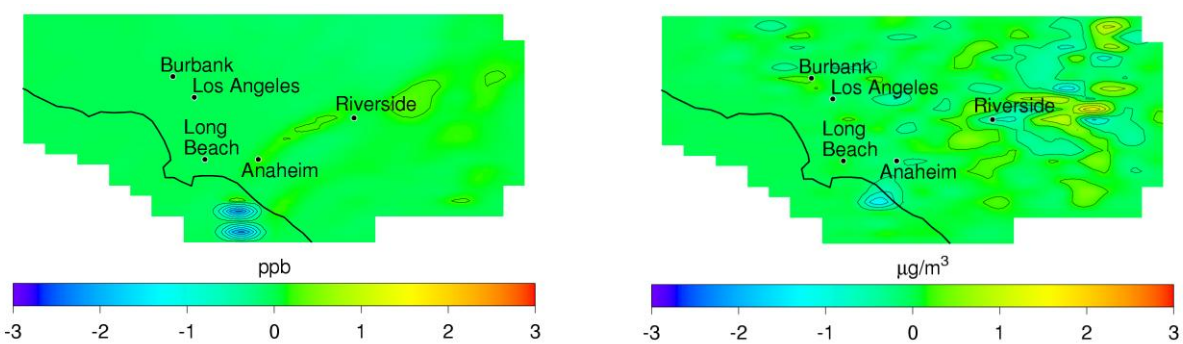
	Net emissions changes in % with respect to total 2005 emissions	
Pollutant	**Scenario 1: ICE - AES Huntington Beach**	**Scenario 2: MCFC - AES Huntington Beach**
NO_X	0.04	-0.01
CO	0.01	-0.03
VOC	0.07	0.00
PM_{10}	0.00	-0.02
SO_2	0.01	-0.02

The changes in 8-hour average O_3 and 24-hour average $PM_{2.5}$ concentrations caused by Scenario 1 and Scenario 2 are presented in Figure 40 and Figure 41, respectively. The removal of the central power plant leads to a reduction in 8-hour average O_3 of 3 ppb (Figure 40a and Figure 41a), and a reduction in 24-hour average $PM_{2.5}$ of 1 μg/m^3 (Figure 40b and Figure 41b). These reductions occur around the location of the power plant. In contrast, the effect of the CCHP is more diffused because the emissions are more widespread than the ones from the power plant. There are minor differences in the air quality impacts between the ICE and the MCFC. In both cases, there is only a slight increase in ozone concentration of less than 1 ppb downwind from Riverside, and mixed increases and decrease in $PM_{2.5}$ concentrations of the order 1 μg/m^3. Decreases in $PM_{2.5}$ are attributed to reduction in secondary formation due to the shutdown of the power plant, whereas increases in $PM_{2.5}$ are attributed to increases in PM emissions and secondary formation due to emissions from CCHP installations.



(a) (b)

Figure 40: ICE DG/CHP Application in Food Retail: Changes in pollutant concentrations: (a) effects on peak 8-hour ozone concentrations, (b) effects on 24-hour average PM2.5



(a) (b)

Figure 41: MCFC DG/CHP Application in Food Retail: Changes in pollutant concentrations: (a) effects on peak 8-hour ozone concentrations, (b) effects on 24-hour average PM2.5

6.1.7. Conclusions

For the application of DG/CHP at grocery stores on a basin wide level, the impact of extensive deployment of DG/CCHP in the sectors can result in the elimination of one or more of the large central power plants in the SoCAB. Analysis of energy balances suggests that CCHP could meet a large fraction of the high temperature refrigeration needs, in addition to all the electric loads. As a result, CCHP systems could reduce the installed capacity needed to provide the same electric and thermal loads to food retail stores. CCHP systems with internal combustion engines could reduce the installed capacity by 30%, whereas as CCHP systems with molten carbonate fuel cells could reduce the need by 15%.

Owing to the relatively low number of applications as compared to the total basin energy consumption (3.6 %), the effect on the overall air quality as measured by ozone and PM2.5 is zero to slight improvement relative to the pre-deployment situation. The impacts in emissions are in general small, if compared with total emissions from all sources in the basin. The emission changes due to the deployment of CCHP and the removal of a central power plant correspond to less than 0.1% of the total basin-wide emissions. However, the reduction of emissions produced by the power plant shutdown is concentrated in one point, whereas the increase in emissions from CCHP installations is spread throughout a large area of the domain. As a result, the changes in pollutant concentrations are still noticeable.

The removal of the power plant produces a reduction in 8-hour average O3 and in 24-hour average PM2.5 of 3 ppb and 1 μg/m3, respectively, in the proximity of the power plant. In contrast, increases in 8-hour average O3 and in 24-hour average PM2.5 attributed to CCHP occur in areas around Riverside, and are of the order of 1 ppb and 1 μg/m3.

6.2. Near Field Impacts Modeling

6.2.1. Modeling Conditions

In this work, the NO_x dispersion from a typical micro turbine generator (MTG) is studied. There are numerous parameters that can affect the plume dispersion near a MTG. local wind speed, exhaust temperature, exhaust NO_x concentration, exhaust velocity, direction of exhaust velocity and adjacency to a wall. In this study, the effects of exhaust velocity magnitude and direction, exhaust height relative to the ground, wind speed, and adjacency to two different shapes of wall are examined.

Table 11: Plume Model Parameters:

Description	Default Condition	Others
Ambient Conditions		
Temperature	80 deg F	
Wind Speed	15 mph; positive Z-direction	5 mph, positive Z-direction

Prime Mover	Microturbine; 60 kW w/ integral waste heat recovery	
Dimensions (L x W x H)	6 ft x 2.5 ft x 7.75 ft	
Exhaust Conditions		
Mass flow	~ 1 lb / sec	
Temperature	350 deg F	
Exhaust diameter	10 inches	
Exit Velocity (actual)	37.8 ft/sec (25.77 mph)	
Species Concentration	NOx: 10 ppmv	
Exit Plane Height	8.25 ft above ground level	15 ft, 20 ft, 25 ft and 30 ft
Exhaust Direction (non vertical exhaust representative of rain dampers on exhaust exit)	vertical	+ 45 deg from vertical (with wind direction) -45 deg from vertical (against wind direction)
Model Domain		
Spatial Volume	550 ft length (Z direction) x 100 ft height (Y-direction) x 50 ft width (X-direction)	**See** Figure 42
Spatial Limits	Z-Direction: -50ft to +500 ft Y-direction; 0 ft to +100 ft X-direction; -25 ft to +25 ft	
Location of exhaust	Z=0, X=0, Y = 8.25	Y=15ft , 20ft, 25ft, and 30ft
Flow Field	Unobstructed (semi-infinite)	Full Wall: Upstream "building", full extent in X-direction, 25 ft tall in Y-direction, location from Z= -50 ft to -15 ft Half Wall: Upstream building, half of x-domain (X=0 to X=25 ft), 25 ft tall, location from Z=-50 ft to -15 ft

Boundary Conditions	Ground: Wall (no transport) Top: Pressure outlet (0 psi gauge) Lateral Sides (XZ planes): Velocity Inlet (tangential velocity = wind speed) Wind Entrance plane (XY plane): Velocity Inlet Wind Exit plane (XY plane): Pressure outlet (0 psi gauge)	

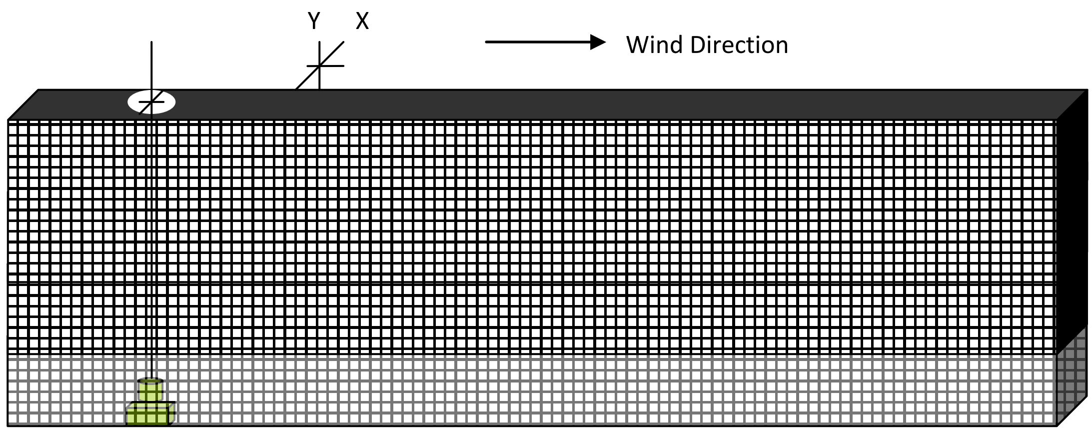


Figure 42: Domain for analysis (not to scale)

6.2.2. Domain and Grid Generation

The dimensions of domain including micro turbo generator (MTG) are defined in a way to make sure the boundaries don't have considerable effects on flow field. Therefore, based on preliminary studies, these dimensions are picked for this study, as shown in Table 11, are relatively large as compared to the microturbine. Ultimately, the results indicate that the Y and Z directions as defined are larger than necessary by a factor of two.

Accurate computations of turbulent flows require careful mesh generation. While high accuracy is desired, turbulent fluctuations play a significant role in the transport of all parameters. Consequently, it is critical to ascertain that the turbulent quantities are suitably resolved. Due to the strong interaction of the mean flow and turbulence, numerical results for turbulent flows, especially mass transport results, are more sensitive to grid quality dependency than those for laminar flows.

The grid for the current investigation was created in Gambit using unstructured tetrahedral mesh elements. Due to symmetric domain for most of cases, mesh generated in half of domain in those cases. However, for the cases without symmetric condition, mesh generated for entire domain. To capture more information along exhaust of MTG while wind travels downstream, an adaptive grid was utilized to refine mesh in this region. All computations are carried out on an 8 node Beowulf cluster each with 4 GB RAM. The CPUs are AMD Opteron 2.6GHz CPUs with 1MB cache. The operating system is Redhat 4 64 bit OS Advance Server and the nodes are connected via a GigE Nortel switch.

Table 11 identifies the breadth fo the parameter variations identified for the analysis. Table 12 identifies the specific cases and conditions for the analyses as well as some information on the gridding and the iterations of the analyses necessary for proper convergence of the models.

Table 12 Studied Cases

#	**Case**	**Number of Cells**	**# of Iteration**
1	8.25ft exhaust plane; vertical discharge	284,570	750
2	8.25ft exhaust; +45 tilted (exhaust tilted in direction of wind)	284,570	750
3	8.25ft exhaust; -45 tilted (exhaust tilted against direction of wind)	284,570	750
4	8.25ft exhaust vertical discharge 5 mph wind	284,570	750
5	15ft exhaust; vertical discharge	370,642	800
6	15ft exhaust; +45 tilted	370,642	800
7	15ft exhaust; -45 tilted	370,642	800
8	Full Wall(FW) 25 ft height; 8.25ft exhaust; vertical discharge	893,799	4,000
9	Half Wall(HW) 25 ft height; 8.25ft exhaust; vertical discharge	285,138	1,800
10	FW; 20ft exhaust, vertical discharge	352,998	2,750
11	HW; 20ft exhaust; vertical discharge	1,055,190	3,200
12	FW; 25ft exhaust; vertical discharge	404,770	2,750
13	HW; 25ft exhaust; vertical discharge	1,353,124	6,250
14	FW; 30ft exhaust; vertical discharge	463,250	6,000
15	HW 30ft exhaust; vertical discharge	2,044,041	5,500

6.2.3. Computational Approach

In current design practice, Reynolds-Averaged Navier-Stokes (RANS) computations are the Computational Fluid Dynamics (CFD) tools for investigation of the velocity and plume dispersion criteria. This is a result of the relative tradeoff between computation time (relatively short for RANS) and accuracy (hard to assess a priori).

In the context of RANS modeling, various models exist to close the set of equations. The major classifications of modeling approaches for the turbulent stresses are Eddy Viscosity model, Reynolds Stress model and the Algebraic Stress model [24]. The κ - ε turbulence is classified as an eddy viscosity model, with two partial-differential equations for compressible and incompressible fluids [24]. The Realizable κ - ε model, as used in this effort, is reportedly the most reliable κ - ε turbulence model for the jet in cross flow problem [25].

Governing equations and flow analysis

Since some features of the flow field can be interpreted by means of looking at the role of different parameters in the governing equation, those associated with the κ - ε turbulence model are discussed. For an incompressible steady flow with constant viscosity, the Reynolds averaged governing equations for mass, momentum, species concentration, turbulent kinetic energy and its dissipation rate for the κ - ε model can be written in the following format 26

$$\frac{\partial}{\partial x_i}(\rho U_i \Psi) = \frac{\partial}{\partial x_i}\left(D_\Psi \frac{\partial \Psi}{\partial x_i}\right) + S_\Psi \qquad (1)$$

The equations are specified in detail in Table 13. It should be noted that Ψ is an arbitrary variable which can be replaced with an appropriate variable according to Table 13 and D_Ψ is the diffusion term.

Table 13: Detailed governing equations

Ψ	D_Ψ	S_Ψ
1	0	0
U_j,**j=1,2,3**	μ_t	$-\partial P/\partial x_j + \partial\{\mu_t(\partial U_i/\partial x_j)\}/\partial x_i$
S	μ_t/Sc_t	0
k	μ_t/σ_k	$G - \rho\varepsilon$
ε	μ_t/σ_ε	$(\varepsilon/k)(c_1 G - c_2\rho\varepsilon)$

μ_t, which is the turbulent viscosity, is defined as:

$$\mu_t = C_\mu \rho k^2/\varepsilon \qquad (2)$$

[24] J.E. Bardina, P.G. Huang, and T.J. Coakley, 1997, " Turbulence modeling validation, testing, and development", NASA TM 110446.

[25] Y. Xiao and H.W. Tang, 2006, "Numerical simulation of a horizontal momentum jet in cross-flow", *J. Hydrodynamics*, Vol 18, pp. 118-125.

[26] BE Launder, DB Spalding, "The numerical computation of turbulent flows", Computer Methods in Applied Mechanics and Engineering archive, 1990

Where C_μ=0.09, c_1=1.44, c_2=1.92, σ_k=1.0 and σ_ε=1.3. S represents the species concentration and Sc_t is the turbulent Schmidt number.

FLUENT v6.3 is used to solve the flow field governing equations. Since the node-based averaging scheme is known to be more accurate than the default cell-based scheme for unstructured meshes, most notably tetrahedral meshes, this scheme has been applied [27]. The pressure interpolation scheme, PRESTO (PREssure Staggering Option) has been applied because of relatively better prediction in the present work. Second order upwind scheme have been used for the momentum, species, and elements of turbulence. Under relaxation factors have been chosen in a way to get the convenience convergence.

6.2.4. Result and Discussion

In this section, typical numerical results for each case are provided. For each section, two contours of NO_x are presented in X=0, and Y=5 ft. The X=0 plane indicates the typical behavior of plume dispersion vertically along the wind direction; with the plane presented being along the centerline of the exhaust at X=0, the concentrations presented are indicative of the greatest extend of plume penetration downwind of the microturbine. The second contour presented is a view “from above looking down” at the turbine at an elevation of Y=5 ft.; this perspective provides information on the lateral dispersion of the plume at a level that is likely to be most sensitive to the intake and respiration of the human population. In addition, the velocity contour is provided in each plane to obtain more information about flow field. All the dimensions are in units of “ft” and velocities are in units of “miles per hour”.

[27] FLUENT 6.3 Documentation

8.25ft Stack Height; Vertical exhaust

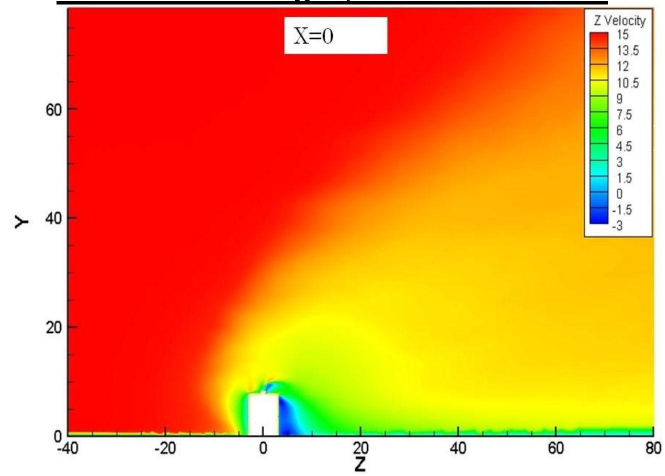


Figure 43 Velocity 8.25ft Stack Height Vertical exhaust

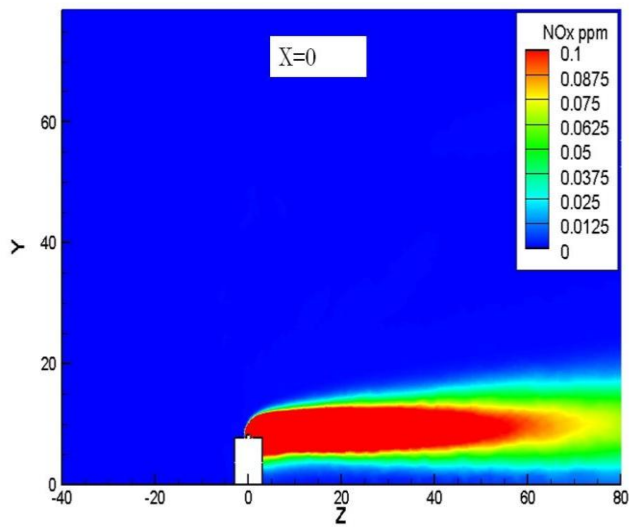


Figure 44: NO_x Concentration for 8.25ft Stack Height Vertical exhaust

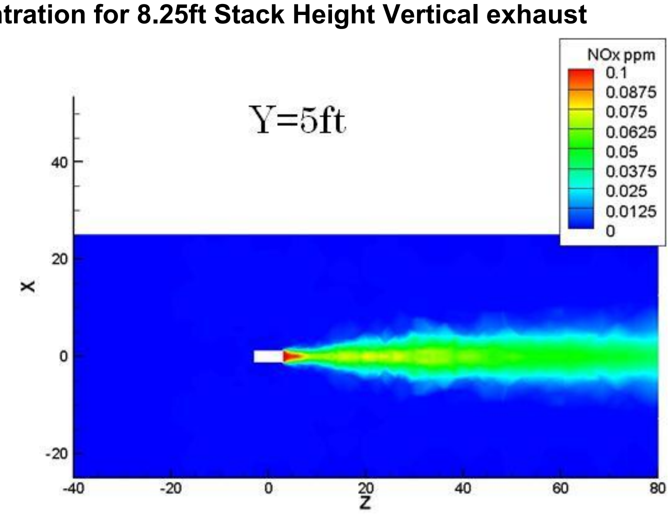


Figure 45 NO_x Concentration; Y=5ft for 8.25ft Stack Height Vertical exhaust

8.25ft Stack Height +45 tilted (with wind)

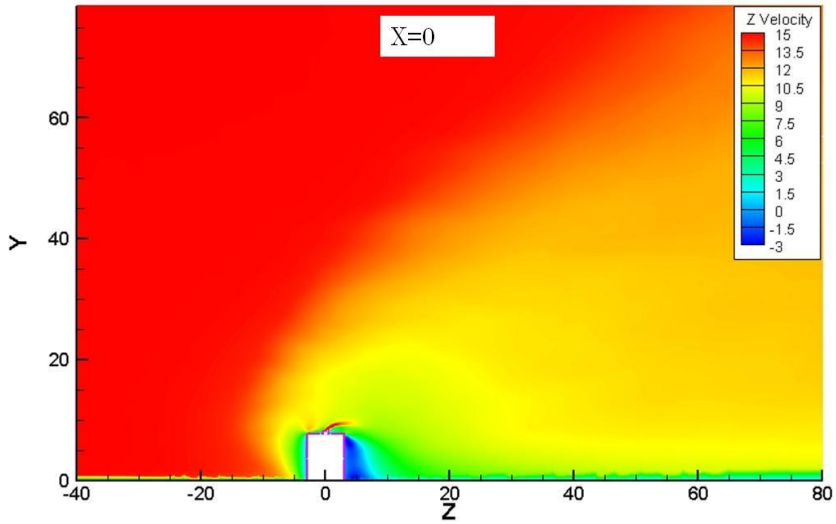


Figure 46 Velocity for 8.25ft Stack Height +45 tilted

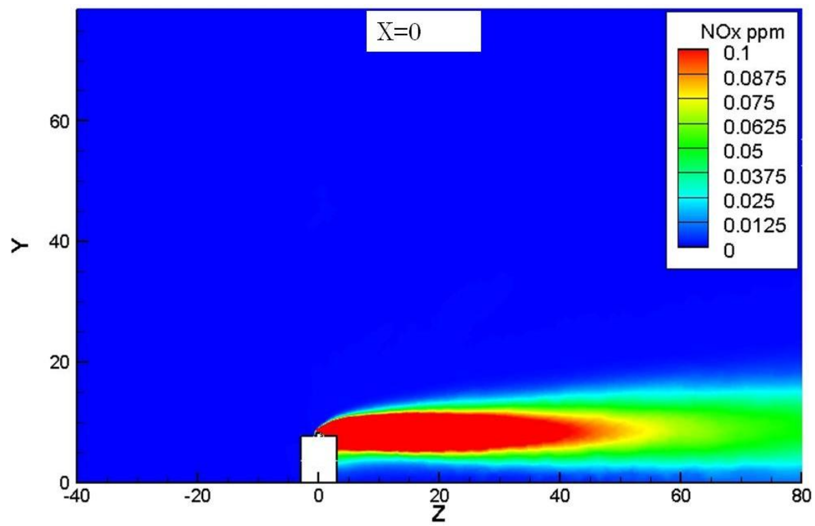


Figure 47 NO_x Concentration for 8.25ft Stack Height +45 tilted

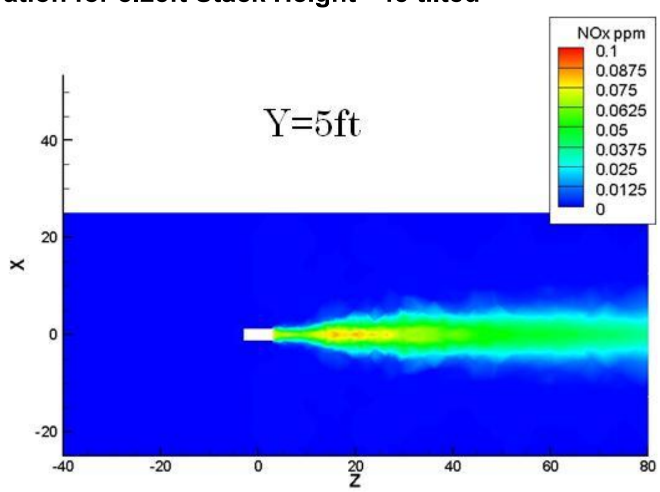


Figure 48 NO_x Concentration; Y=5ft for 8.25ft Stack Height +45 tilted

8.25ft Stack Height -45 tilted (against wind)

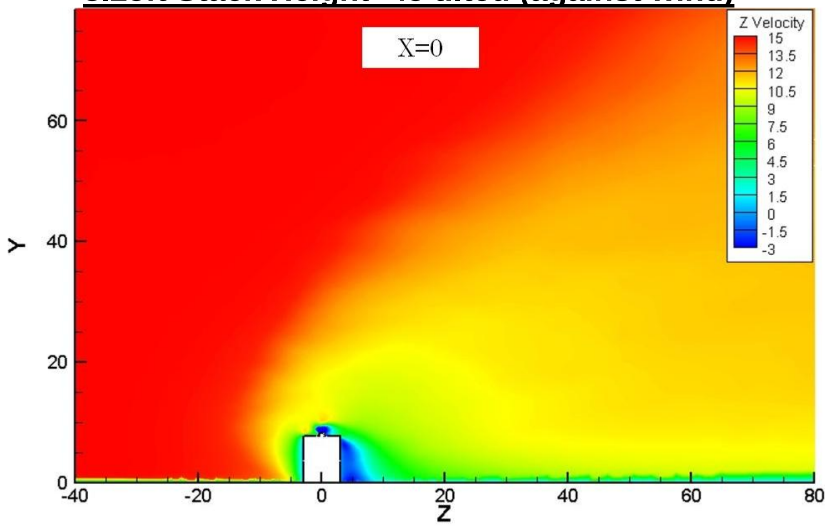


Figure 49 Velocity for 8.25ft Stack Height -45 tilted

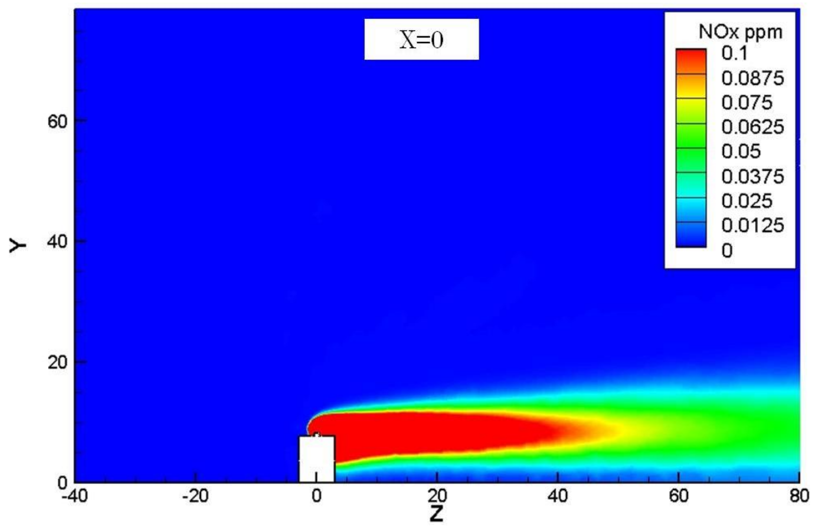


Figure 50 NO_x Concentration for 8.25ft Stack Height -45 tilted

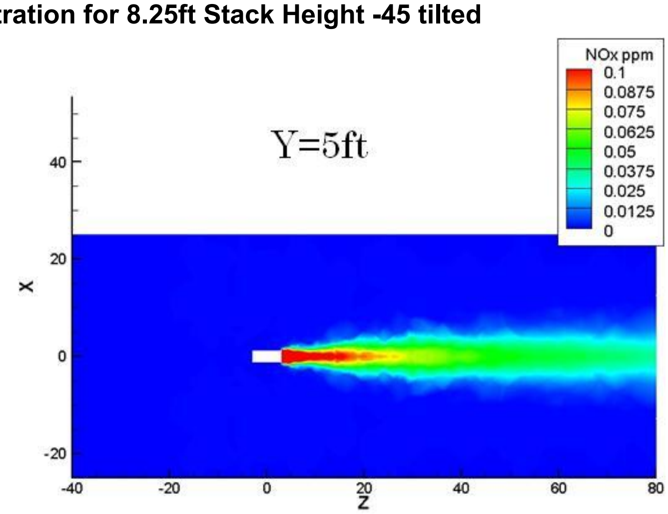


Figure 51 NO_x Concentration; Y=5ft for 8.25ft Stack Height -45 tilted

8.25ft Stack Height; 5mph Wind Velocity

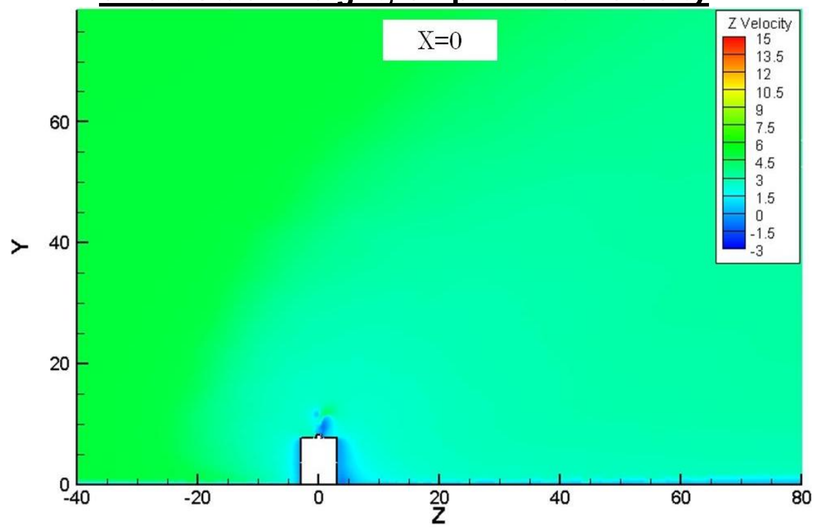


Figure 52 Velocity 8.25 ft stack height vertical exhaust (5mph wind speed)

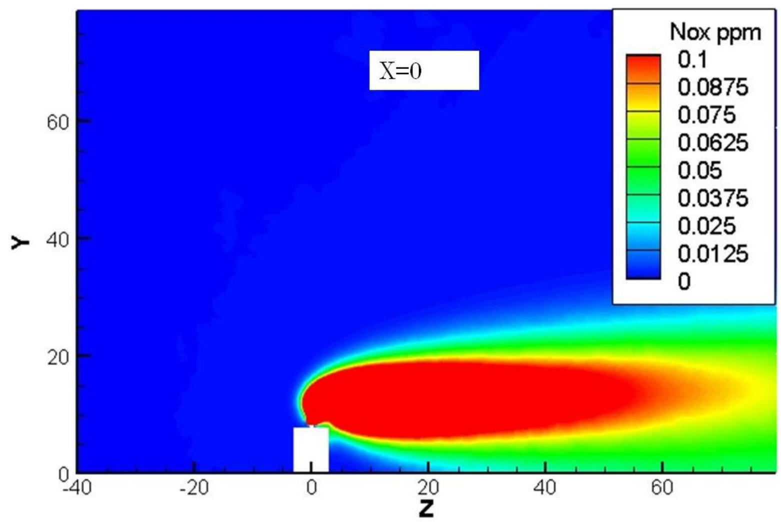


Figure 53 NO_x Concentration for 8.25ft Stack Height (5mph wind speed)

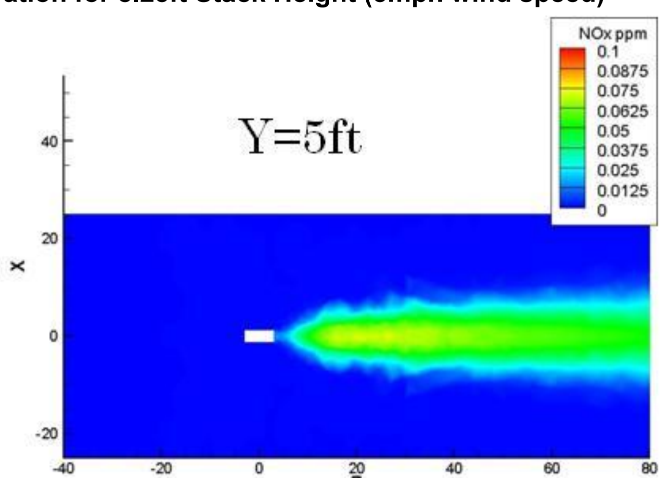


Figure 54 NO_x Concentration; Y=5ft for 8.25ft Stack Height (5mph wind speed)

15ft Stack Height Vertical Exhaust

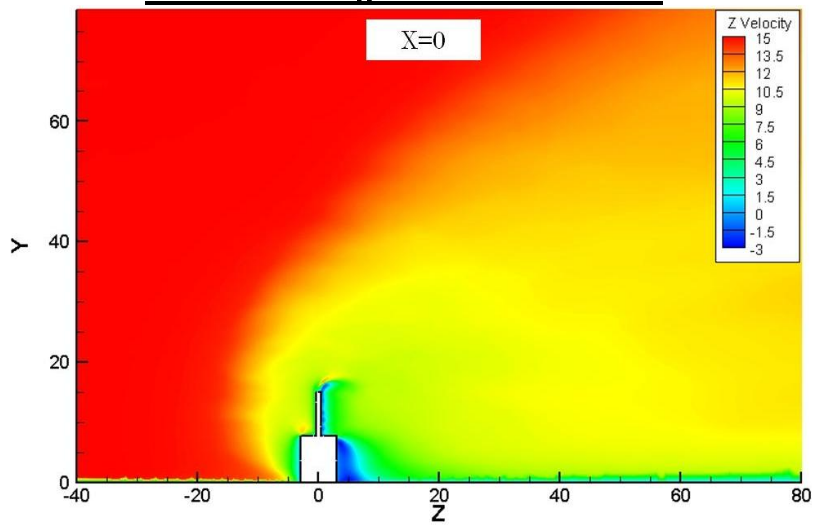


Figure 55 Velocity for 15 ft Stack Height vertical exhaust

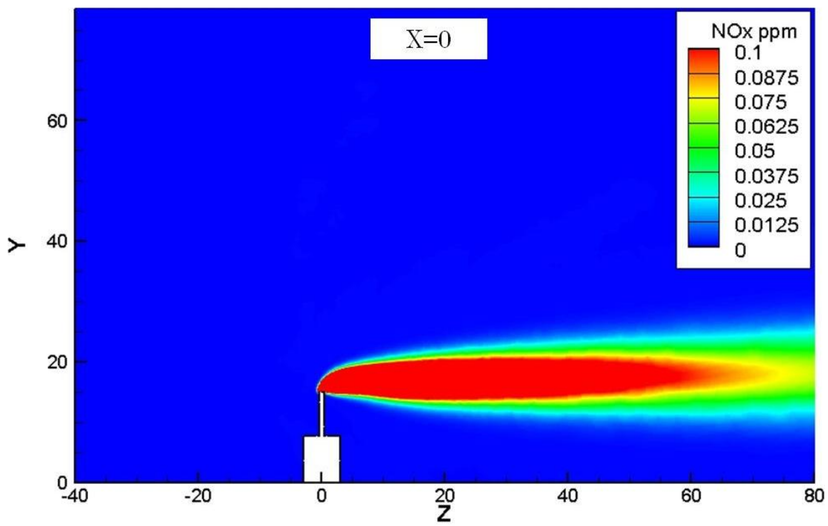


Figure 56 NO_x Concentration for 15ft Stack Height vertical exhaust

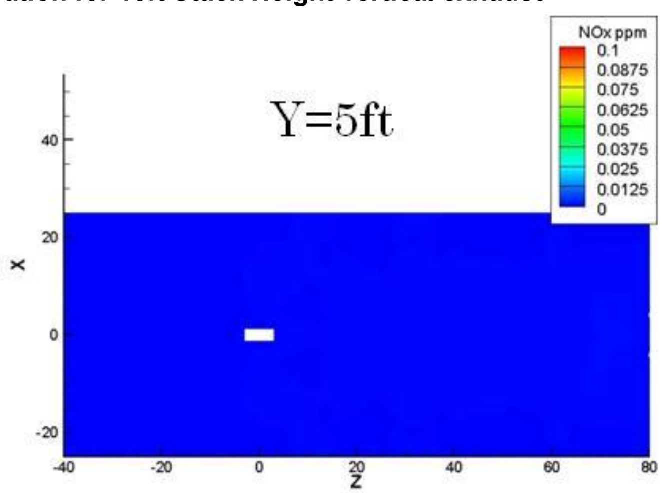


Figure 57 NO_x Concentration; Y=5ft for 15 ft Stack Height

<u>**15ft Stack Height +45 tilt (with wind)**</u>

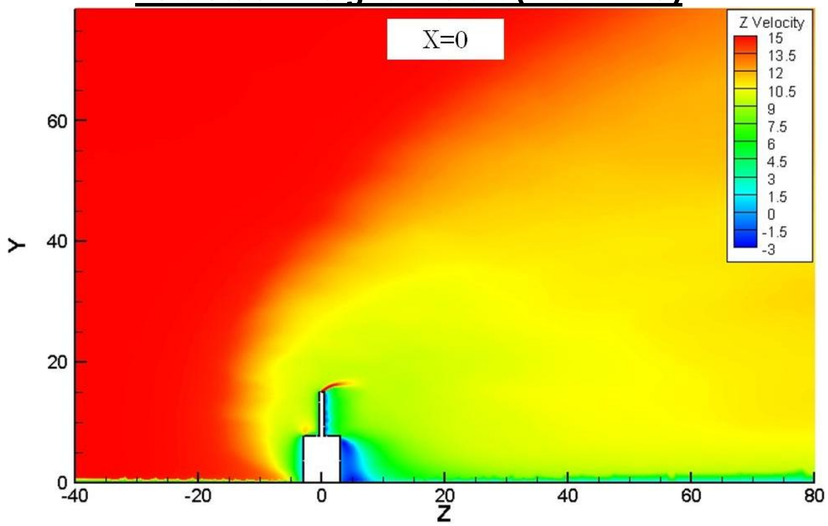


Figure 58 Vertical velocity for 15ft Stack Height +45 tilted

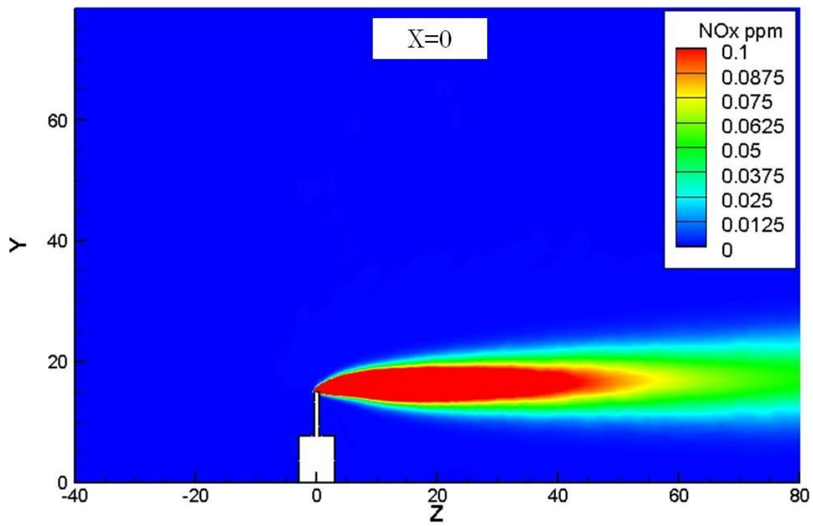


Figure 59 NO_x Concentration for 15ft Stack Height +45 tilted

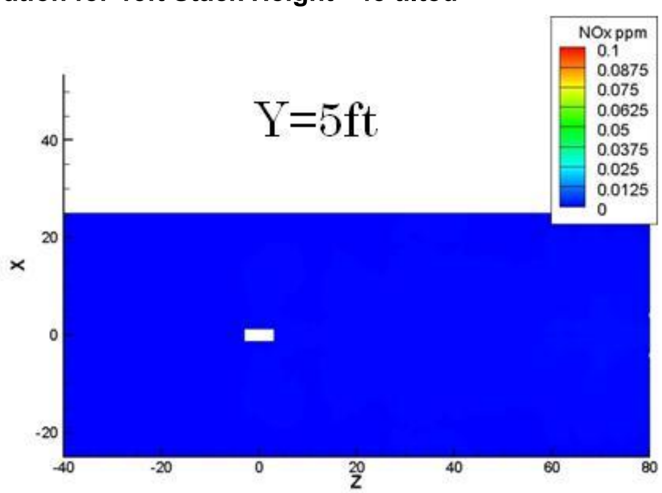


Figure 60 NO_x Concentration; Y=5ft for 15 ft Stack Height +45 tilted

15ft Stack Height -45 tilted (against wind)

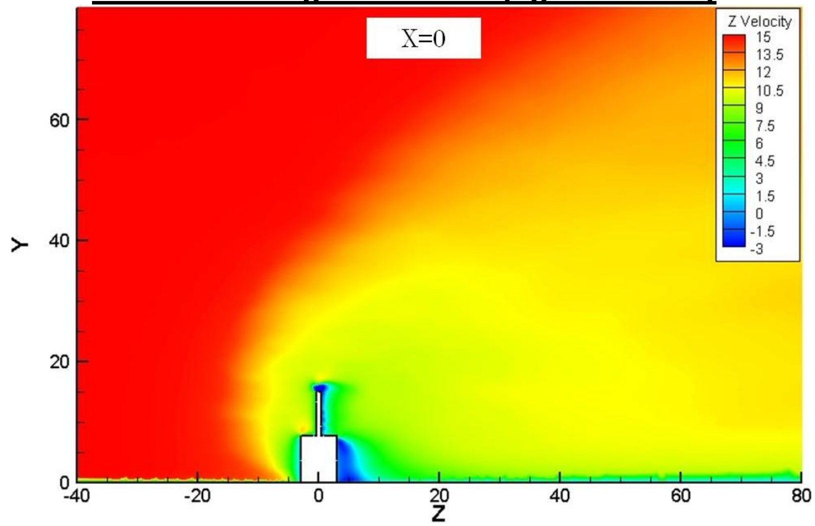


Figure 61 Velocity for 15 ft stack height -45 tilted

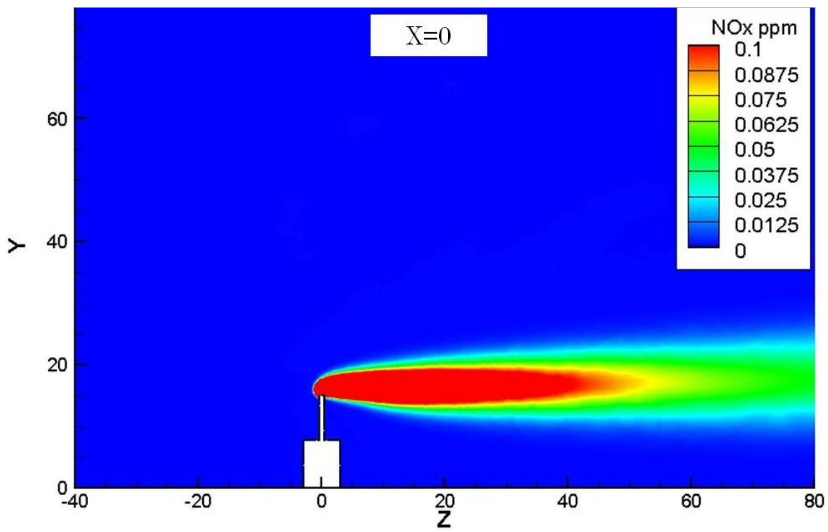


Figure 62 NO_x Concentration for 15ft Stack Height -45 tilted

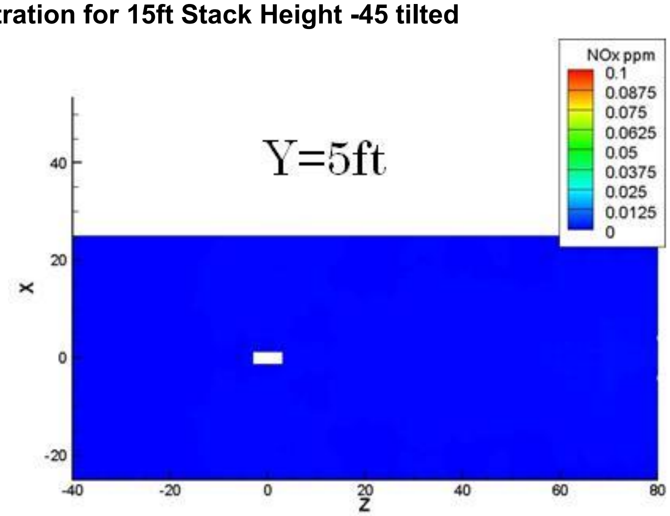


Figure 63 NO_x Concentration; Y=5ft for15 ft Stack Height -45 tilted

25ft Height full wall (FW), 8.25ft Stack Height

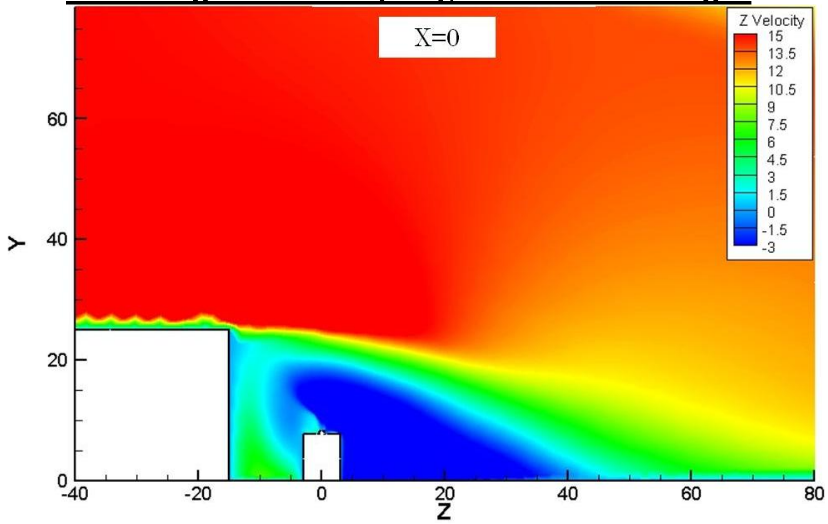


Figure 64 Velocity for FW, 8.25ft stack height

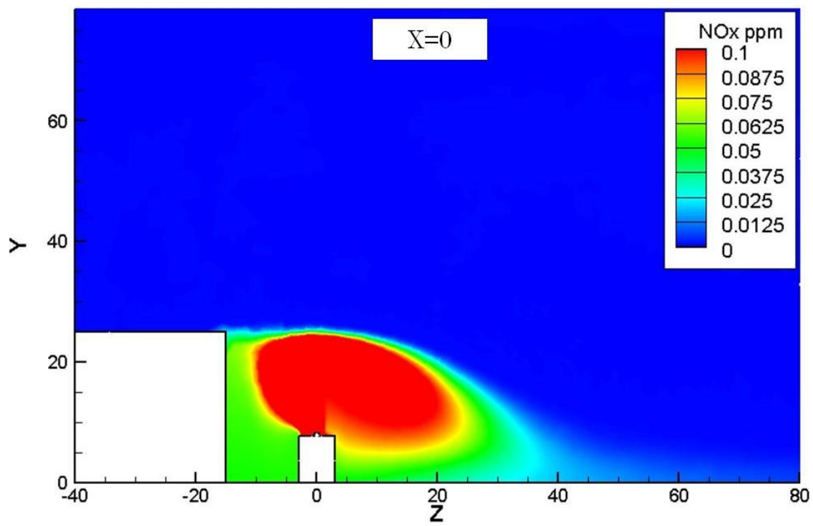


Figure 65 NO_x Concentration for FW, 8.25ft stack height

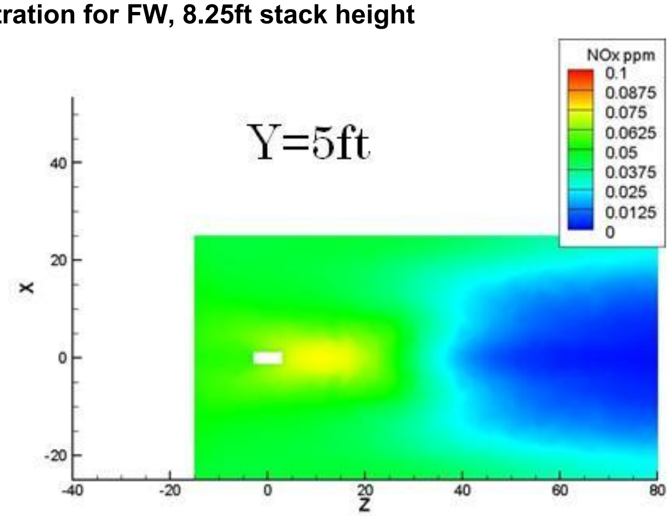


Figure 66 NO_x Concentration; Y=5ft for FW, 8.25ft stack height

25ft Height Half Wall (HW), 8.25ft Stack Height

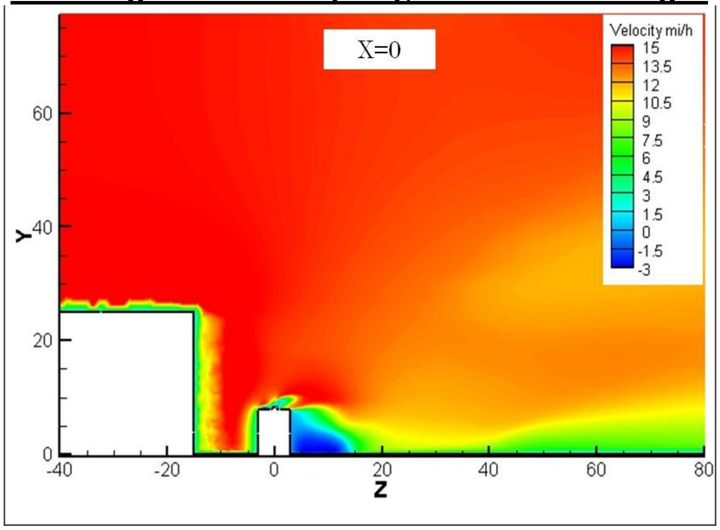


Figure 67 Velocity for HW, 8.25ft stack height

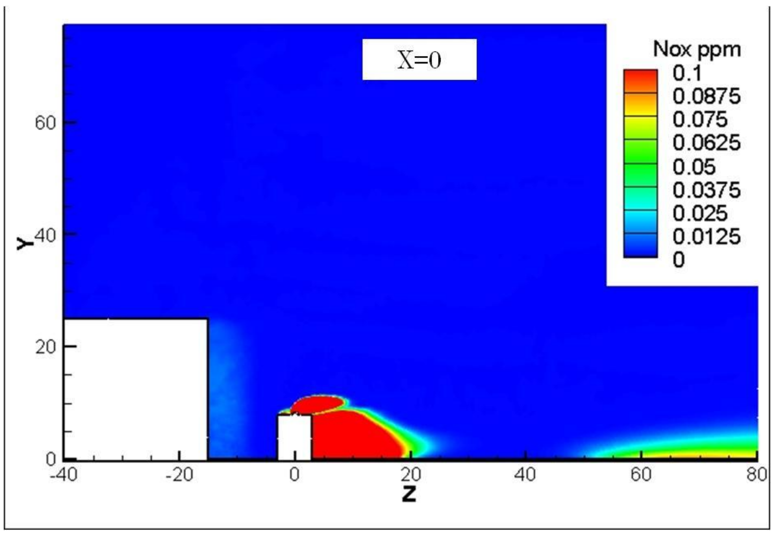


Figure 68 NO_x Concentration for HW, 8.25ft stack height

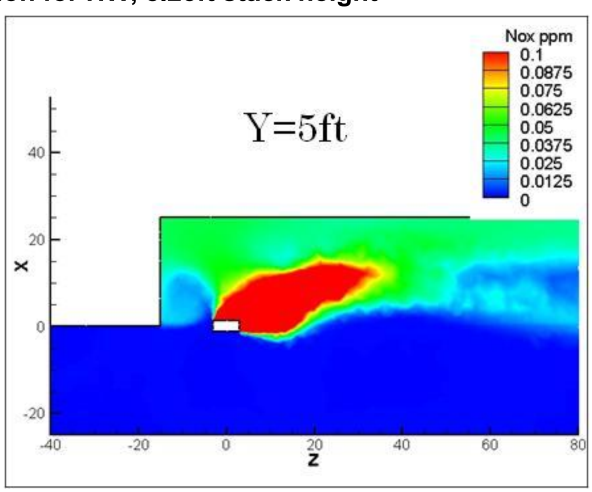


Figure 69 NO_x Concentration; Y=5ft for HW, 8.25ft stack height

25ft Height Full Wall (FW), 20ft Stack Height

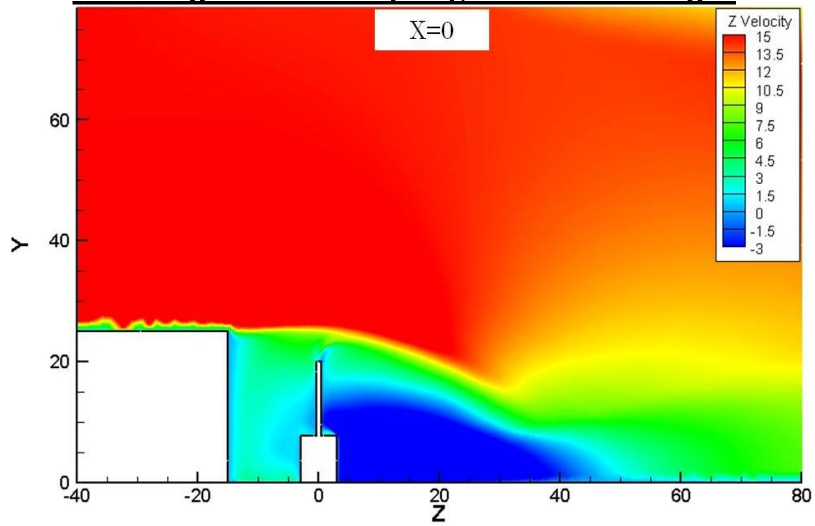


Figure 70 Velocity for FW, 20ft stack height

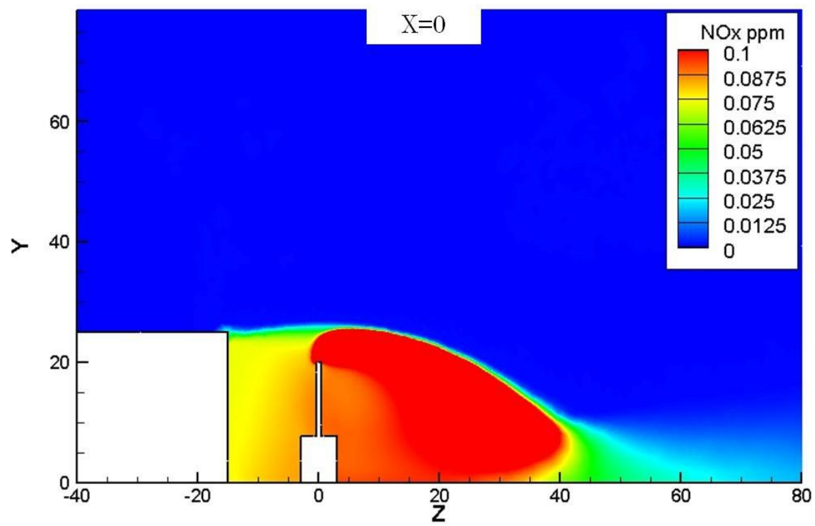


Figure 71 NO_x Concentration for FW, 20ft stack height

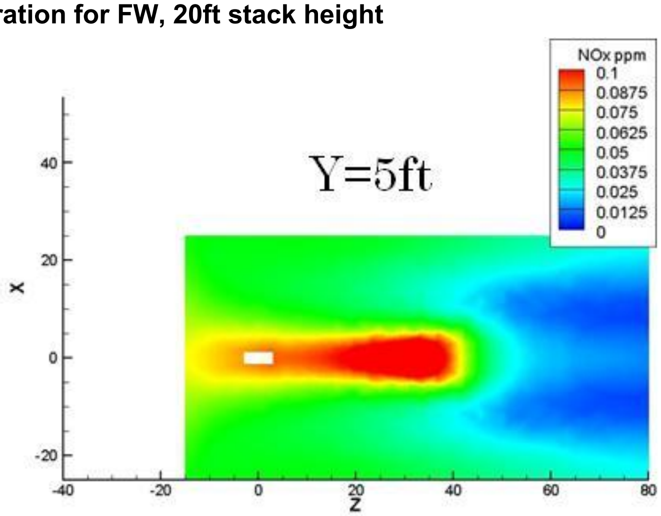


Figure 72 NO_x Concentration; Y=5ft for FW, 20 ft stack height

25ft Height Half Wall (HW), 20ft Stack Height

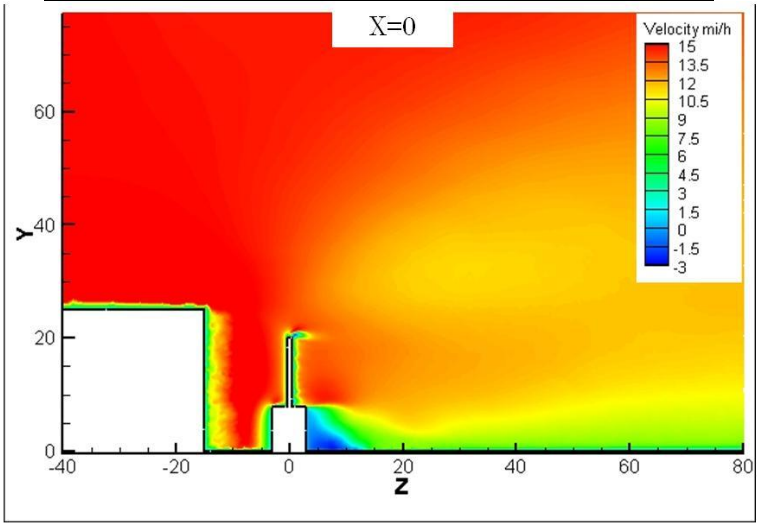


Figure 73 Velocity for HW, 20 ft stack height

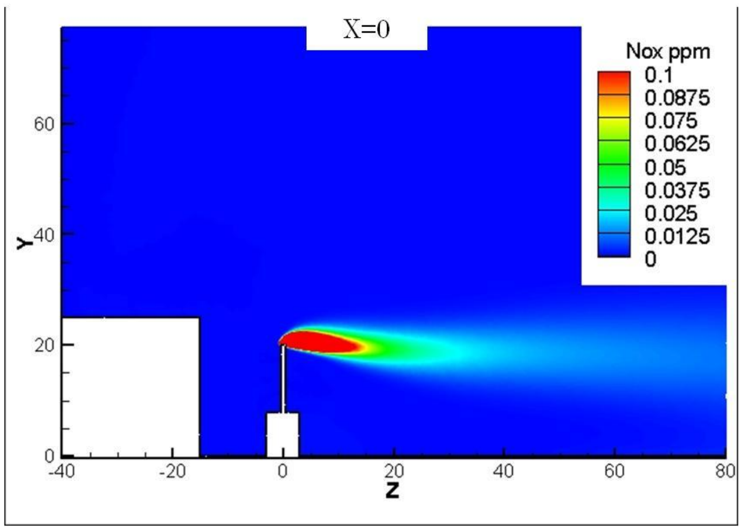


Figure 74 NO_x Concentration for HW, 20ft stack height

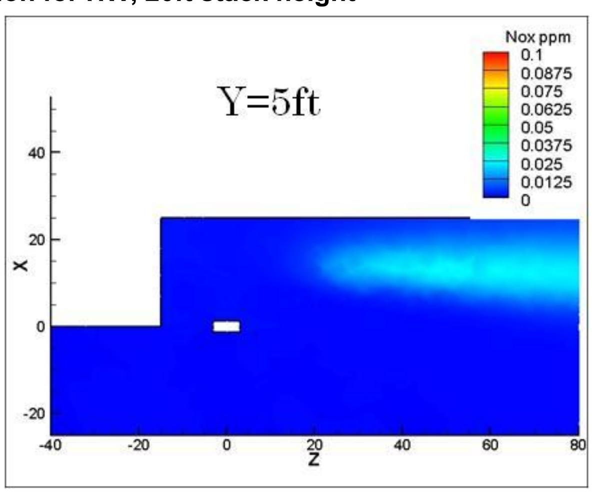


Figure 75 NO_x Concentration; Y=5ft for HW, 20 ft stack height

25ft Height Full Wall (FW), 25ft Height

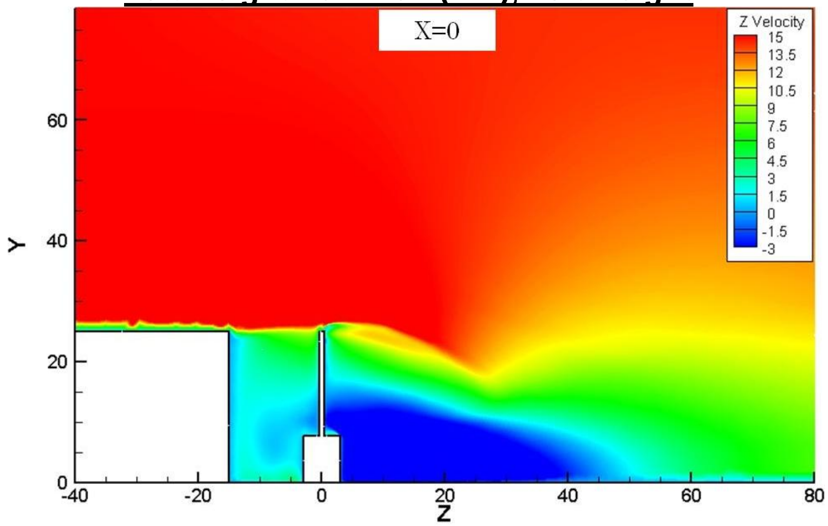


Figure 76 Velocity for FW, 25 ft stack height

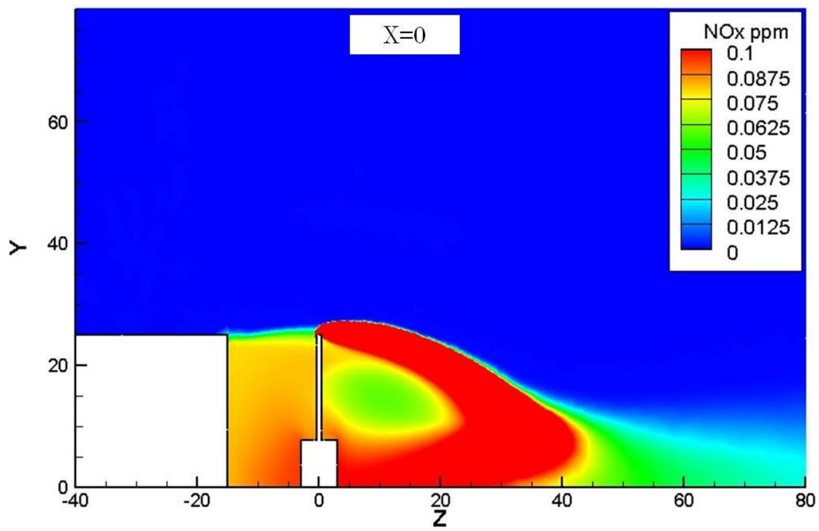


Figure 77 NO_x Concentration for FW, 25ft stack height

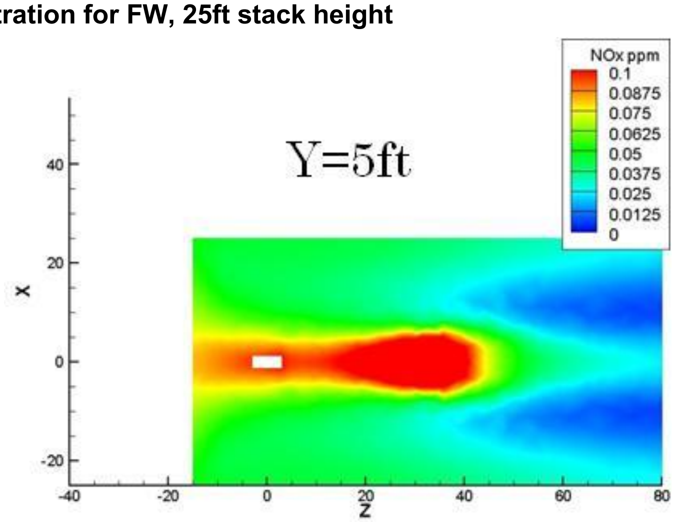


Figure 78 NO_x Concentration; Y=5ft for FW, 25 ft stack height

25ft Height Half Wall (HW) , 25ft Height Stack

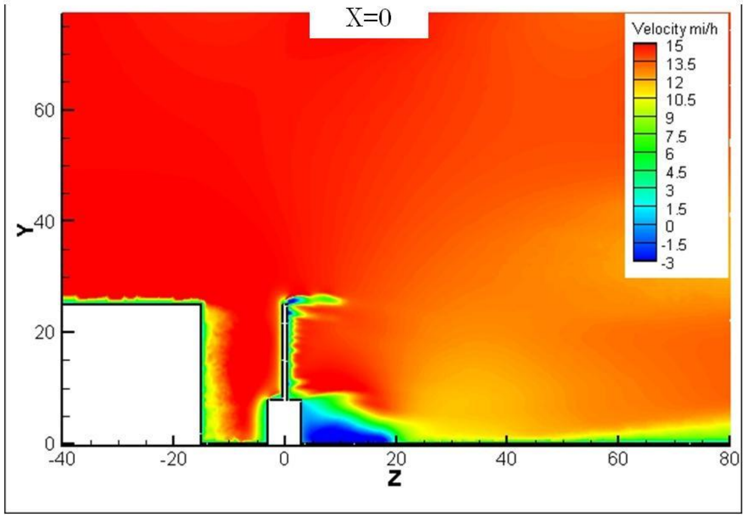


Figure 79 Velocity for HW, 25ft stack height

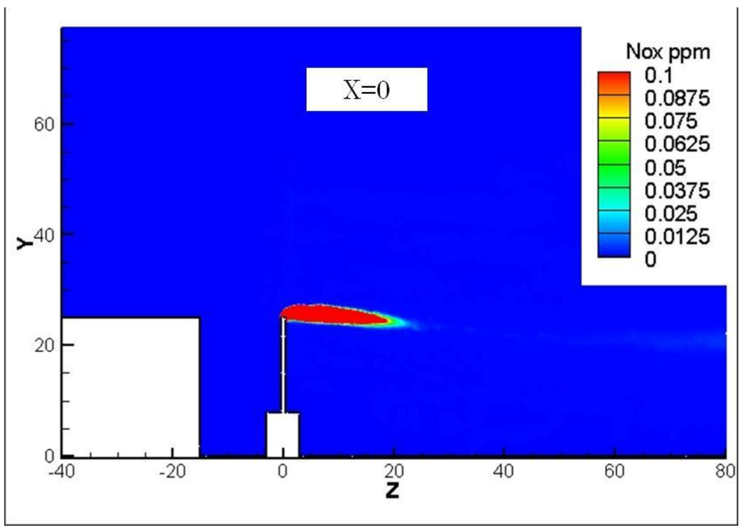


Figure 80 NO_x Concentration for HW, 25ft stack height

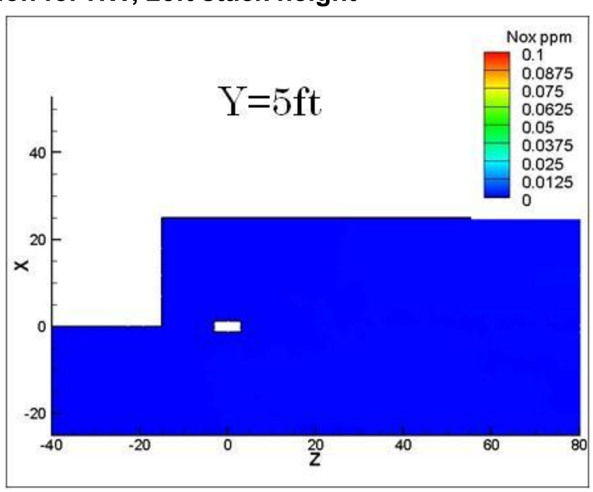


Figure 81 NO_x Concentration; Y=5ft for HW, 25 ft stack height

25ft Height Full Wall (FW), 30ft Height

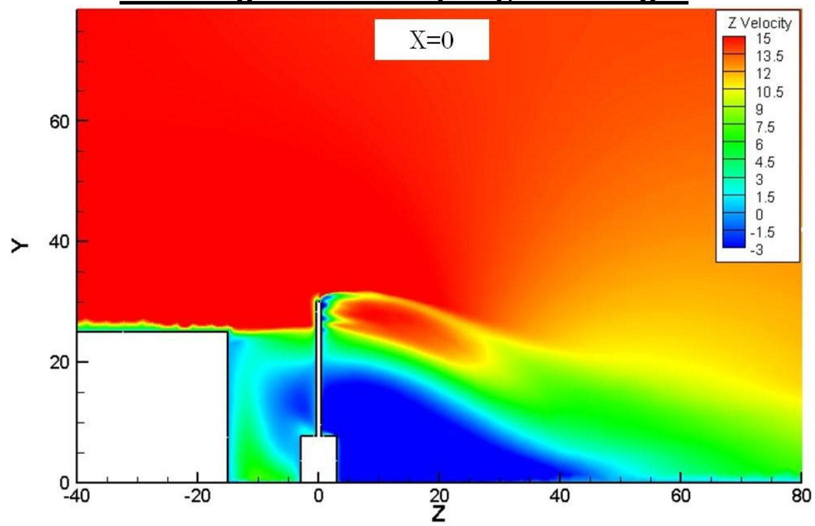


Figure 82 Velocity for FW, 30ft stack height

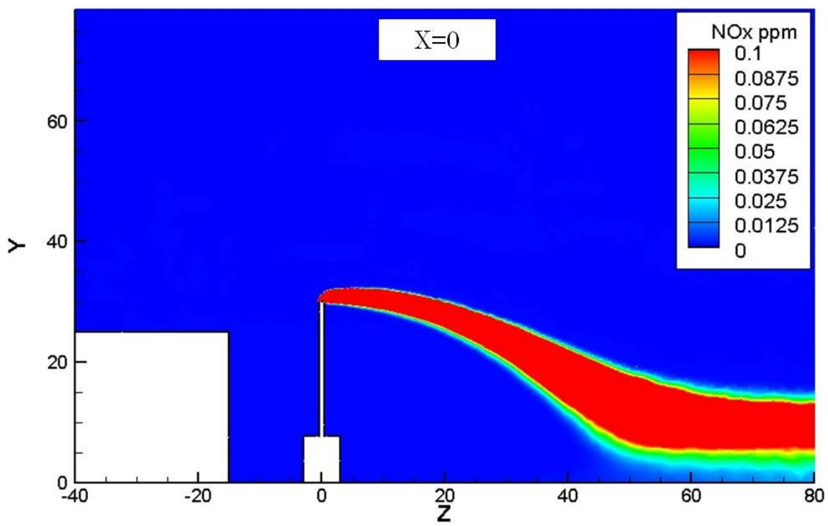


Figure 83 NO_x Concentration for FW, 30ft stack height

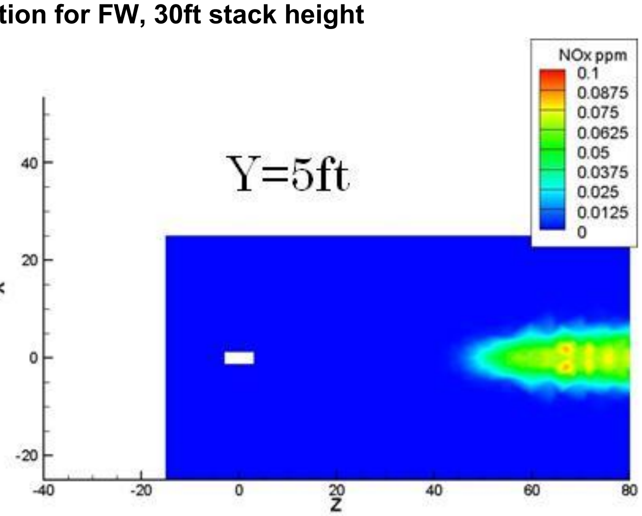


Figure 84 NO_x Concentration; Y=5ft for FW, 30 ft stack height

25ft Height Half Wall (HW), 30ft Height

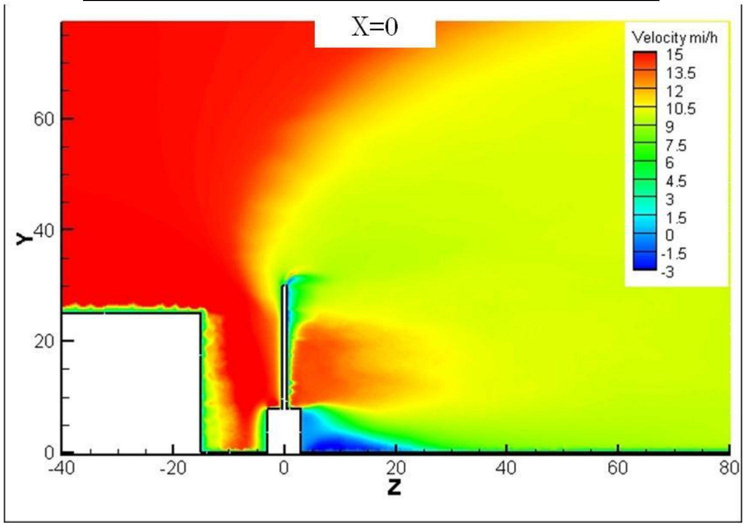


Figure 85 Velocity for HW, 30ft stack height

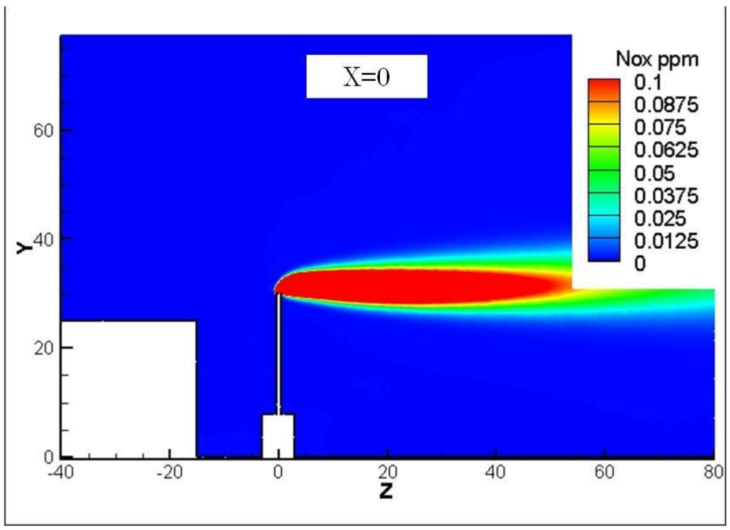


Figure 86 NO_x Concentration for HW, 30ft stack height

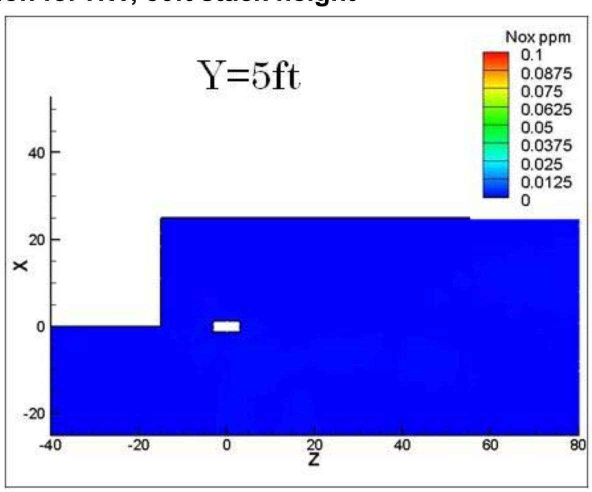


Figure 87 NO_x Concentration; Y=5ft for HW, 30 ft stack height

6.2.5. Conclusions

The effects of DG/CCHP on both the near field adjacent to the system and the South Coast Air Basin (SoCAB) were analyzed through computer modeling. The results suggest very rapid dispersion of the plume. In the presented results, it is vital to note that the "red" section as presented represents the limit of 0.1 ppm NO_x, two orders of magnitude lower than the exhaust gas concentration. The presence of upstream obstructions such as a building or a wall does, not unexpectedly, result in a more disrupted field and greater near field impact. However, mixing and dispersion are still quite rapid and the resulting concentration levels are not greatly increased as compared to the free field cases. Overall, in and of itself, the microturbine exhaust has minimal effect on the near field concentration levels at human population impact elevations. However, when compared to the current California Ambient Air Quality Standard of 0.18 ppm for 1 hour or the new EPA standard of 0.1 ppm for 1 hour, the contribution from the microturbine are on the order of these limits. Hence, when combined with existing background levels, the impact of the microturbine may result in local emissions exceeding the limits.

Another pertinent observation is that, as previously stated, the dispersion as modeled in these simplistic cases is very rapid. Essentially all of the dispersion and region of influence occurs within 100 ft of the DG stack. As we have noted, the effect of specific buildings and multiple buildings as well as other meteorological influences such as vertical mixing from ground radiation effects have not been included. The myriad of possible scenarios is unbounded. While the expectations of increased flow perturbation and mixing would seemingly suggest even faster dispersion of the plume, for the sake of the analysis of the near-field population exposure, a distance of 100 ***meters*** (328 ft) from the DG stack will be considered as the near field.

6.3. Near Field Population Analysis

With an understanding of the extent of potential plume influence, the effect of the widespread deployment of DG/CHP on resident permanent population was evaluated. This evaluation was limited to Southern California, a region for which extensive geographical information system (GIS) data was readily available. The region evaluated represents an area of 96.17 billion square meters and has a population of 17.9 million.

The results of the effort are based upon the GIS information on population density within sectors (zip-codes), the location and shape of facilities in the six sectors of interest, and the intersection /overlap of the permanent residential zones as defined by GIS with the 100 meter extension of the boundaries of the facilities defined on the GIS map. Note that the data identifies permanent population. There is no way within the GIS to understand the transient population that might be influence by the presence of a DG system. For example, the GIS analysis permitted identification of the number of permanent population that was within the 100 meter boundary of a hospital's region of influence but does not address the number of patients, staff, or people visiting a hospital during the day, all considered to be transient rather than permanent residents.

Another caveat relative to the analysis is that the population identified was based upon the geographical overlay of the facility's region of influence with the permanent residential map. There was no analysis of meteorological effects, primarily wind, to generate a subset of the field of influence consistent with prevailing weather conditions nor abnormalities of the weather condition. It is understood that consideration of the prevailing winds would greatly reduce the affected population.

Finally, of the six sectors of interest to the program (hotels, hospitals, large commercial office, jail/prison, colleges/university, and food/grocery), the impacts of food and grocery were not included in the analysis. The GIS data base available for the analysis did not discriminate grocery stores from other "retail" facilities (strip malls, large retail, etc). Since grocery stores comprise only a fraction of the retail sector, inclusion of all retail in the analysis would unrealistically skew the results to larger affected population. As such, the impact of grocery stores, expected to actually have more influence per facility on resident population than most of the other sectors given the service to residents and proximity to residential areas, could not be directly assessed.

6.3.1. GIS Field

The analysis of DG deployment affected population was limited to the Southern California region as defined in Figure 88. The analysis required three data sets:

- Land use definition
- Geographical shape files.
- US Census demographic census data

The land use definition was used to discriminate between the "business" land use for a variety of sectors, including those of interest to this program and residential areas The spatial mapping of land use in the southern California region was initially developed by Aerial Information Systems, Inc. (AIS) for the California Association of Governments (SCAG) in 1990. This data has been periodically updated, with the most recent update in 2005 (used in this analysis). The data is collected using aerial photography, computer based photo interpretation techniques, and digital natural color imagery. For "hard to identify photo signatures" were flagged for on-site visits performed by AIS field survey teams to ensure the accuracy of the interpretations. (Web link: http://www.aisgis.com/projects/SCAG.html)

The Topologically Integrated Geographic Encoding and Referencing (TIGER) database is a digital database of geographic features covering the entire United States. They can be downloaded publically as shape files which run in software based geographical information systems (GIS). TIGER files are developed and updated periodically by the US Census bureau, with the latest update in 2005.The shape files do not include demographic data, but it can be linked to the Census Bureau's demographic data. (Web link: http://www.census.gov/geo/www/tiger/overview.html)

The US Census data base is used in conjunction with the TIGER shape files to create a spatially resolute demographical file which can be inputted into GIS.

Figure 88: Map of Analysis Area

6.3.2. Analysis

For the analysis, DG/CHP systems were assumed to be installed at all facilities representative of the sectors of interest in this study;

- Commercial office buildings of all heights (note that the program identified large commercial office which is facilities >100,000 sq-ft. However, GIS does not provide this discrimination but rather one based upon building height with the choices of 1- 10 stories, 11-40 stories, and 40+ stories).
- Universities and colleges
- Hospitals and major health care facilities
- Hotels and motels

- Correctional facilities (jails/prisons)

As previously mentioned, grocery stores were not included in the analysis; the SCAG land use database aggregated grocery stores under the generic heading of "retail stores" and they could not be separately resolved.

Of these six sites, all of them, with the exception of grocery stores, were mapped on ArcGIS. These sites were mapped using the 2005 SCAGLU database and expressed as a 2D polygons with discrete areas. Of the mapped sites, all of them were given a 100 meter (real world) buffer around their perimeters. Using this buffer, the mapped sites were increased to include the 100 meter buffer. Figure 89 is an example of a set of hotel buildings in Anaheim. The dark blue are the actual land areas of the buildings while the lighter blue regions are the 100 meter buffer that was imposed onto the actual building.

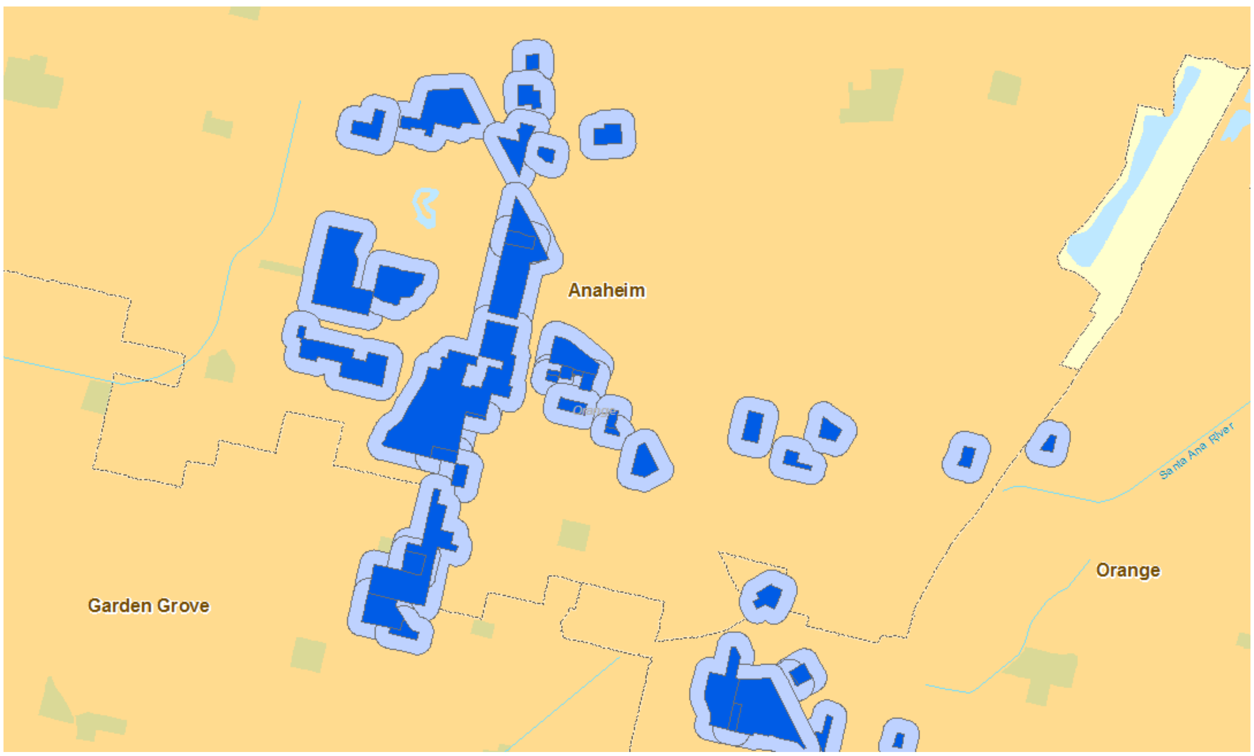


Figure 89: Example - Hotel Buildings for DG Siting

The detailed analysis of the impacts takes the information of the site use and the surrounding buffered area and overlays it with the specific residential areas in the proximity of the DG site. The intersecting area are identified (refer to Figure 90)

It is difficult to assess the daytime population density in each of the areas that are potentially impacted by DG installations. The Census data provides the population density but that is reflective of people within a dwelling or space; it does not reflect daytime departures for jobs, school, or other "errands' as a part of day-to-day life. With the exception of Commercial Office, all of the sectors identified for study would likely be 24/7 operation to address the 24/7 needs for electric power and HVAC or other waste heat recovery loads. Hence, an analysis of nighttime impact would define a maximum bound for number of effected. The exception of Commercial Office space is reflective of a "normal" occupancy of 6 am to 6 pm, Monday through Friday. It is not expected that Commercial Office would operate 24/7. However, in the spirit of trying to understand the maximum possible population effected, inclusion of the Commercial Office sector is provided in the summary of results with the aforementioned caveat.

The detailed night time approach makes a highly resolute estimate of the total of people that could be affected by the installation of DG at the potential sites at night. The assumption made for the night time analysis is that all of the night time population is distributed in residential buildings. Although this is not strictly true, it can be assumed that the majority of the population sleep at night and come home to sleep.

The first step in this analysis was to redistribute the average population density of a zip code to population densities of different residential areas within that zip code. Four discrete residential areas were used in this analysis. The spatial and informational data for these areas

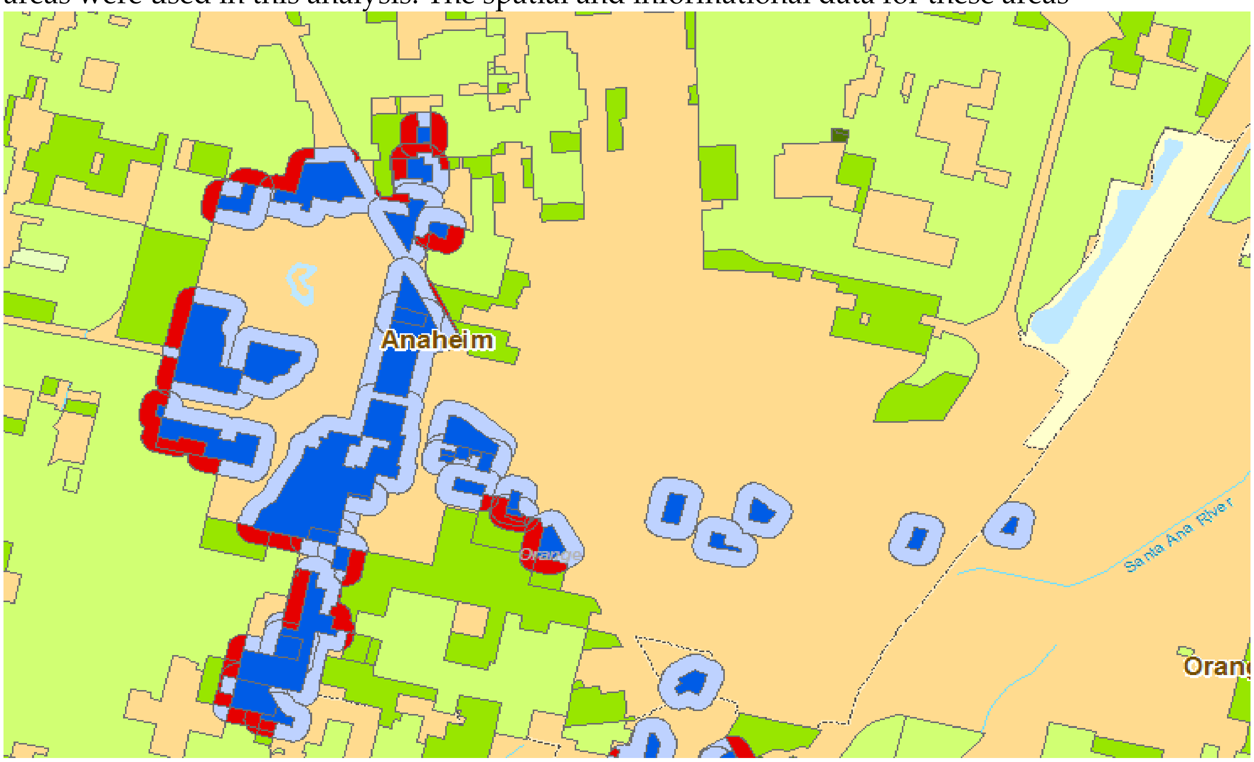


Figure 90: Intersection of Residential and DG buffer Zones

were obtained from the 2005 SCAGLU database. The residential areas were categorized by their population density (in units/acre). The four categorizations are:

> 18 units/acre

> 6 units/acre

> 2 units/acre

<2 units/acre

To be able to use the population densities, they were consolidated into a unique number derived from taking the average of the range. For the very high density group, a conservative assumption of 20 units/acre was used because there was no upper bound. Thus the four residential areas are:

- Very high density (20 units/acre)
- High density (12 units/acre)
- Medium density (4 units/acre)
- Low density (1 units/acre)

Next, the population density of each residential area was determined based on the zip code they fell into. To do this, the following algorithm was used to generate a unique scalable density (ϱi) for each zip code i:

$$\rho_i = \frac{(20 * A_{VH} + 12 * A_H + 4 * A_M + A_L)}{Population\ of\ the\ Zip\ Code\ i}$$

Where:

A_{VH} = Area of very high density residency
A_H = Area of high density residency
A_M = Area of medium density residency
A_L = Area of low density residency

To compute the actual population density (Pi,j) for each unique zip code i and residential area j, scaling factors was applied to ϱi based on the four density categories. Thus, for example, Pi,VH is derived by applying a scaling factor of 20 to ϱi.

The second step in the analysis was to find the overlap between the residential areas and the buffered DG sites. This was accomplished using an area intersect method on ArcGIS. Figure 90 shows the overlap areas in red, while the residential area and buffered DG sites are shown in green and blue, respectively. The darker green areas signify a residential area with higher density.

The overlap spots were cropped out and their surface areas were determined.

Finally, the affected population was calculated by multiplying the overlap surface areas by the actual population density (Pi,j) for each residential area that it overlaps. For areas that fall under two or more residential areas, the total area of the overlap was assumed to have the higher population density (Pi,j). The reasoning behind this was to ensure a more conservative estimate.

6.3.3. Population impacts

Figure 91 shows the potential application of DG/CHP in the 6- sectors of interest relative to the residential population for the Southern California area. Following the analysis scenario described previously and mapping out the 100 meter range of influence, Figure 92 identifies the affected areas/regions that are within 100 meters of a potential DG/CHP installation associated with the 6-sectors of interest throughout the area.

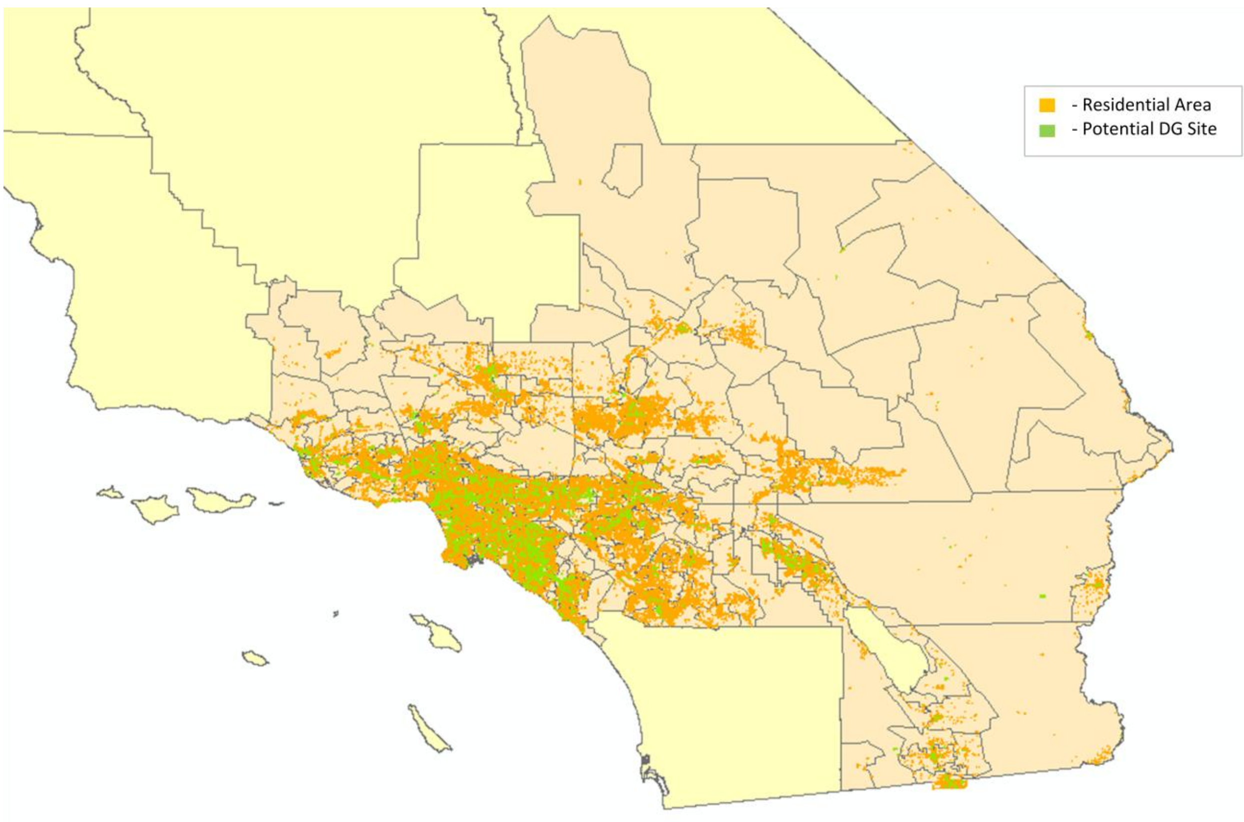


Figure 91: Residential Population and possible DG/CHP installations

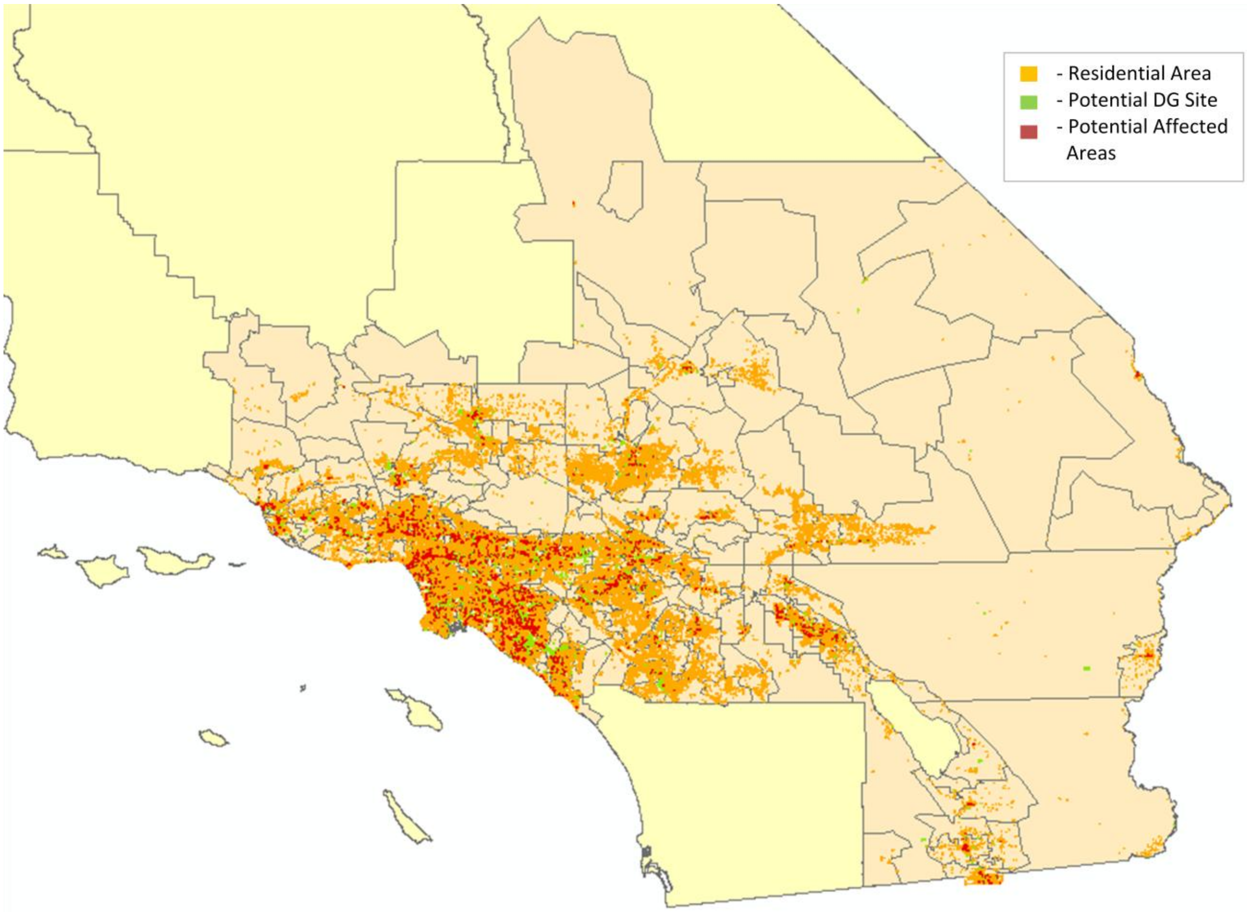


Figure 92: Regions of Residential within 100 meters of DG/CHP

The results of the analysis are shown in

Table 14. Listed are the sectors, the number of facilities in each sector in the Southern California region, the number of facilities in each sector that have buffer zones that intersect with residential areas, and the number of effected residents. Note that a daytime estimate of impact is also included; lacking firm information on the exact impacts of population migration during the day (job, school, etc), an assumption of 50% is applied to all of the nighttime affected numbers. Also note that the Commercial Office numbers are shown for nighttime as a basis for assessing the daytime numbers only.

Table 14: Potential Residential Population Impact of DG

Sector	# in Region	# Impacting Residential Area	Night time		Daytime
			Max	6pm-6 am	6 am-6 pm
Commercial Office					
1 – 10 stories		7272	403,171	0	201,585
11-40 stories		319	88,429	0	44,215
40+ stories		7	3,493	0	1,746
Hotels	1413	598	142,970	142,970	71,485
Hospitals	388	330	89,424	89,424	44,712
College/University	655	296	89,161	89,161	44,580
Jail/Prison	156	57	4,850	4,850	2,425
Totals				**~326,400**	**~410,750**
% Population affected (17.9 million for region)				**1.8%**	**2.2%**

6.3.4. Summary

The relative exposure analysis effort and results must be considered in the context of the data and the assumptions necessary at this level of study:

- A buffer zone was defined as 100 meters even though the plume modeling effort suggested that mixing and dilution of the exhaust plume to 1% of the exit plane levels occurred within 100 ft.
- Meteorological conditions (e.g wind velocity and direction, ground mixing) are not included. All residents that intersect with the buffer zone are included in the "affected" population
- The size, distribution, and orientation of the building(s) comprising the facility and the immediate surroundings are not included.
- The stack height of the DG is assumed to be at approximately 8 ft (as used in ground level plume modeling).

- The daytime residential density distribution is not known
- The Commercial Office building sector includes all office structures rather than limiting itself to "large commercial" as was identified in the study as the appropriate sector.
- The location of the DG system with a "facility" is not considered but rather is assumed to be at the facility boundary and the 100 meter buffer is established uniformly around the boundary of the facility. In reality, the DG is a point source located within the facility (at some location to be determined on a site by site basis) ; the 100 meter buffer zone would then be established from the point source

As such, the values provided are expected to significantly over-estimate the affected population. Additionally, recall that the plume is diluted within the 100 meter distance to levels comparable to the ambient air quality standards; hence even if the plume does interact with a population base within the 100 meters, the exposure to pollutant levels exceeding the ambient air quality standards is predicated on the existing air quality. Finally, the effect of exhaust stack height was not addressed. Extending the height of the exhaust stack could have significant impact on the dispersion of the plume and the definition of the buffer zone. At the extreme, if a DG system was located on the roof of a multi-floor building (11+ floor office building), it is highly unlikely that the plume effect would ever reach the residential areas in the immediate surroundings.

7.0 Conclusions and Recommendations........

1) All of the sectors analyzed could benefit from the application of DG/CHP.
2) The specific DG system varies from sector to sector based upon the heat load needs versus the electric power needs. The following are identified based upon overall facility energy needs and implementation of DG to meet the overall needs. If a subset of the overall energy needs are to be met with DG, virtually any system can be employed.:
    a. Food and Grocery:
        i. Fuel cell applications would fit for electric power and thermally activated subcooling and HVAC.
        ii. Reciprocating engines are a better fit if including medium temperature cooling loads
    b. Hotels:
        i. Gas turbines are favored based upon the measured heat and electric needs
        ii. Reciprocating engines would be a fit if excess electric power could be place back on grid.
    c. Commercial Office:
        i. Gas turbines are favored based upon the measure heat and electric needs
        ii. Reciprocating engines would be a fit if excess electric power could be place back on grid
        iii. The occupancy loading for commercial office (M-F, 6 am – 6pm) fits well with a peak shaving type application but requires a system that could be cycled on-off daily.
        iv. Facilities that incorporate on-site energy storage (electrical and/or thermal) could benefit from 24/7 operation of a smaller system.
    d. Colleges/University: Gas Turbines
    e. Hospitals:
        i. Reciprocating engines are favored based upon the measured heat and electric needs.
        ii. Gas turbines would be a good fit with some potential loss in efficiency.
    f. Jail/Prison:
        i. All of the State prisons identified in the program do not have HVAC loads for prison population.
        ii. Current heat load is small (hot water) compared to electric. Fuel Cell application would be a fit (as has been demonstrated at some facilities (Santa Rita) but cost and payback are very long.

    iii. If a move to air conditioned prison population is made (ostensibly threatened by litigation by ACLU), gas turbines would be best match for heat and electric loads.

3) Barriers:
    a. Perception of fuel cells especially and to some extent gas turbines is that the systems are too exotic and too costly. Reluctance to invest in "cutting edge" or "bleeding edge" technology.
    b. Reciprocating engines are accepted and understood; a comfortable solution. Air quality rules in SoCAB essentially prohibit the application.
    c. Payback is too long for the "business" applications (food/grocery, commercial office, even hotels which tend to have longer acceptable payback) to invest in system
        i. Emergence of Third Party Providers/ESCO's and power purchase agreements are providing viable alternative to ownership for low/no capital outlay options.
        ii. Food and grocery has an entrenched "bias" towards fluorocarbon based electric refrigeration systems based upon needs for high reliability and historical familiarity. Application of DG with thermally activated cooling would require substantial change to system configurations.
            1. Most immediate possible application is for sub-cooling and HVAC wherein existing lithium bromide based absorption chillers or adsorption chillers could be deployed.
            2. Medium temperature applications (e.g. meat case, dairy, deli) would require implementation of both ammonia based absorption chillers (to provide temps in the 20 F range necessary) and secondary fluid cooling loops (circulation of a fluid to the affected cases). The former exist but have very limited application to date while the latter requires extensive site modifications to incorporate (although it is being utilized in an effort to reduce the quantity of fluorocarbons at grocery stores)
            3. Implementation better suited to new construction than retrofit
    d. Colleges/Universities are slowly adopting the technology and applications (UCI, UCSD, CSUN, PCC, etc). Rapid payback is not a great an issue since the facility is nearly "permanent".
    e. Hospitals are slow to adopt likely due to two factors
        i. Need for power reliability. DG can actually increase reliability when combined with grid but economics do not favor 24/7 generation and there is concern with DG/grid transitions for loss of power
        ii. Perceived hindrance of State OSHPD oversight and approval of system installations.

f. Cost to generate versus electric utility rates typically favors peak use only. However, many of the larger systems that would be employed (large turbines, fuel cells) do not want to be cycled. Break-even or negative cash flow for low cost periods.

g. A limitation on system sizing owing to the prohibition of back feeding to the grid does create some issues.

    i. In all cases, the heat and electric loads could be met by one of the three predominant DG systems: fuel cell, reciprocating engines, gas turbines.

    ii. Allowing back feeding to the grid could allow the identification of more cost effective solutions that would otherwise not be a good heat to electric power match

    iii. A Feed-In-Tariff does provide welcomed flexibility in sizing and cost effective design.

    iv. It is expected that both the flexibility and the modicum of financial compensation provided by Fit will be beneficial to the deployment.

4) Enabling Technology Developments:

    a. Building system that are hydronic based are suitable for implementation of DG/CHP with the thermally activated cooling. Retrofit of a facility that utilizes direct expansion air conditioning (e.g. “Roof Top Units”) is not likely economically viable.

    b. Building systems that allow for on-site energy storage of both electric power and thermal energy (hot and/or cold) would be beneficial for highest efficiency 24/7 operation of system and allow for site to bank on the generated energy for use during periods when it is more valuable.

    c. Building Energy Control systems that are optimized for the on-site system and energy storage

    d. Cost effective and reliable thermal energy storage (both hot and cold)

5) Enabling Policy:

    a. Continuation of economic incentives to push the deployment

    b. Feed in Tariff with favorable rates could have big impact on economics for DG/CHP

    c. Carbon credit valuation

8.0 References..................

9.0 Glossary...............

10.0 Bibliography..............