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# High EER at 46ºC Kingdom of Saudi Arabia Air Conditioner Project

## Draft Final Report


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# Chapter 1: Abstract

This project evaluated the energy savings potential for air conditioning systems for the residential market in the Kingdom of Saudi Arabia. The predominant air conditioners in the Kingdom are near the lowest possible performance standard of 7.5 at T1 and 5.4 at T3. The current international approach to AC design gives insufficient attention to the performance of the air conditioners at the conditions prevalent in the Kingdom. As a result, substantial energy is wasted particularly on peak days.

The Ministry of Water and Electricity commissioned a project to promote air conditioners specifically designed to perform well at hot conditions equaling 46°C.

The results from laboratory testing demonstrated the potential for efficiency improvement of up to 36 percent and peak demand reductions of up to 26 percent on mini-split units. The higher efficiency units present economic, administrative, and technical challenges. Zamil manufacturers a 26,000 BTU capacity mini-split with an EER at T1 of 9.57 (a 21.6% energy savings). The Ministry of Education specifies units with a T1 EER of 8.5 (an 11.6% energy savings).

Due to their confined size and low cost, window units are more challenging than mini-split units. Zamil's higher efficiency 17,500 BTU window units have T1 EERs of 9.2 and 8.9 (18.5% and 15.7% energy savings respectively). These challenges translate into less financially viable and available efficiency improvements for window units.

Based on the technical results, the team recommends that the Kingdom implement strict standards enforcement and upon adequate notice and development time, implement increased minimum efficiencies at high temperatures. To provide proper economics the process should include monetary incentives from the electricity and fuel entities that will most benefit from the improved efficiencies.

**Keywords:** KSAAC, electric peak reduction, peak energy efficiency ratio, sensible cooling, energy efficiency, window air conditioner, room air conditioner (RAC), mini-split air conditioner, air movement efficiency, dry climate, wet climate, evaporator airflow, condenser airflow, Sensible EER, EER, T1, T3.

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# Chapter 2: Executive Summary

## 2-1 Introduction

There was an urgent need for a practical study to raise the values of the efficiency of residential air conditioners in the Kingdom of Saudi Arabia. This study includes an economic and environmental evaluation of achievable energy savings. The original impetus for this study was the prevailing efficiency of air conditioners in the Kingdom. These air conditioners are near the minimum allowable values of Energy Efficiency Ratio (EER) as specified in Saudi standard No. 2663. According to that standard, the minimum EER at T1 (35 degrees Celsius external temperature) is 7.5 BTU / Watt-hour. The standard also specifies a minimum 5.4 BTU / Watt-hour at T3 (46 degrees Celsius external temperature). The current global trend for design and manufacturing of air-conditioners does not give enough attention to the performance of air conditioners in the conditions prevailing in the Kingdom, which include hot dry conditions. The result is excess use of valuable resources, especially in peak days.

Air conditioning systems in the Kingdom are not optimally designed to maximize internal temperature reductions for every Watt Hour of consumption (Sensible EER). High Sensible EER is the goal under the hot and dry climatic conditions. Also, the consumption of electricity and oil in Saudi Arabia was on the rise at an alarming rate between 2009 and 2010. The amount of electricity sold increased by 9.7% and the maximum load by 10.8%. This is consistent with the general trend over the past ten years (SEC 2011).

Air conditioners are the largest users of electricity and they are the cause of the rise of maximum load (peak) of energy consumption across the Kingdom. The increase in the peak consumption puts considerable pressure on the electricity system, since the generating capacity and distribution system must be built to meet the peak loads. At the same time, the Saudi Arabian Standards for allowable AC EER is low and there is no effective commitment to its application.

Many improvements in air conditioner efficiency are only measured by a test that cycles the air conditioner. The tests performed currently in Saudi Arabia are tests that measure the energy efficiency ratio (EER). EER is a steady state test which does not distinguish between air-conditioners that have significant performance changes under cycling or air conditioners that work at a lower speed and more efficiency (variable speed air conditioners). Variable speed compressors have shown significantly higher efficiency over the year. Similarly single-speed compressors, when working periodically between on and off provide opportunities to improve sensible efficiency by more effectively utilizing the condensate for additional cooling.

In the drier portions of the Kingdom, air conditioning is needed to reduce the temperature of the air inside the building rather than provide dehumidification. Air conditioning systems are not optimized to maximize indoor temperature reduction for each watt-hour of consumption under hot and dry ambient conditions. The metric for indoor air temperature reduction (Sensible Cooling) per watt hour of electrical consumption is Sensible EER. Sensible EER is not currently used in rating KSA air conditioners. The current ratings are the sum of sensible cooling and dehumidification per watt hour. The ratings are Total EER, rather than Sensible EER.

The current rating of overall energy efficiency ratio (EER) in the Saudi standards and the minimum norms for it was put at two external temperatures: 35°C (T1) and 46 °C (T3). But the most appropriate in the drier places in the Kingdom of Saudi Arabia is the use of the sensible energy efficiency ("Sensible EER"), which is the overall energy efficiency ratio (EER), multiplied by the sensible heat ratio ("SHR"). The sensible heat ratio is the ratio of the sensible capacity "to reduce the internal temperature" to the overall capacity "including both the internal temperature reduction load and the load of moisture removal (de-humidification)".

Increasing the sensible energy efficiency ratio ("Sensible EER") at a temperature of 46 °C (T3) will reduce the peak load. Increasing the minimum requirement of the energy efficiency ratio by 15% for window air conditioners and 25% for Mini-Splits in the residential sector will reduce the maximum peak load in the Kingdom by 743 MW on the basis that the rate of the "market penetration" in the residential sector is 30%. This increase in efficiency will realize an annual saving in energy of more than 2.10 TWh and savings expand with population growth.

Since the same window and mini-split conditioning units are-often used to cool the non-residential buildings as well, this will lead to more savings in energy in the Kingdom and reduction of peak load.

Implementing the recommendations in this study is estimated to provide the benefits shown in Table 1 and **figure 1**.

**Table 1 Potential Benefits from Program Implementation**

| | Scenario A 5% Compound Growth from 2009 | | Scenario B 8% Compound Growth from 2009 | |
|---|---|---|---|---|
| | Year 1 | Total over 20 Years | Year 1 | Total over 20 Years |
| Fuel Cost Savings (M SAR) | 238 | 112,691 | 328 | 191,773 |
| Fuel Cost Savings (M US$) | 63.5 | 30,051 | 87.5 | 51,139 |
| Generation Cost Savings (M SAR) | 0 | 76,828 | 0 | 92,759 |
| Generation Cost Savings (M US$) | 0 | 20,487 | 0 | 24,736 |
| Avoided Electric Consumption (TWh) | 0.66 | 313 | 0.91 | 533 |
| Electric Peak Avoided (MW) | 231 | 11,166 | 319 | 21,689 |
| CO2 Reduction (kton) | 500 | 237,210 | 689 | 403,677 |
| SO2 Reduction (kton) | 0.82 | 387 | 1.12 | 659 |
| NOX Reduction (kton) | 0.31 | 145 | 0.42 | 247 |

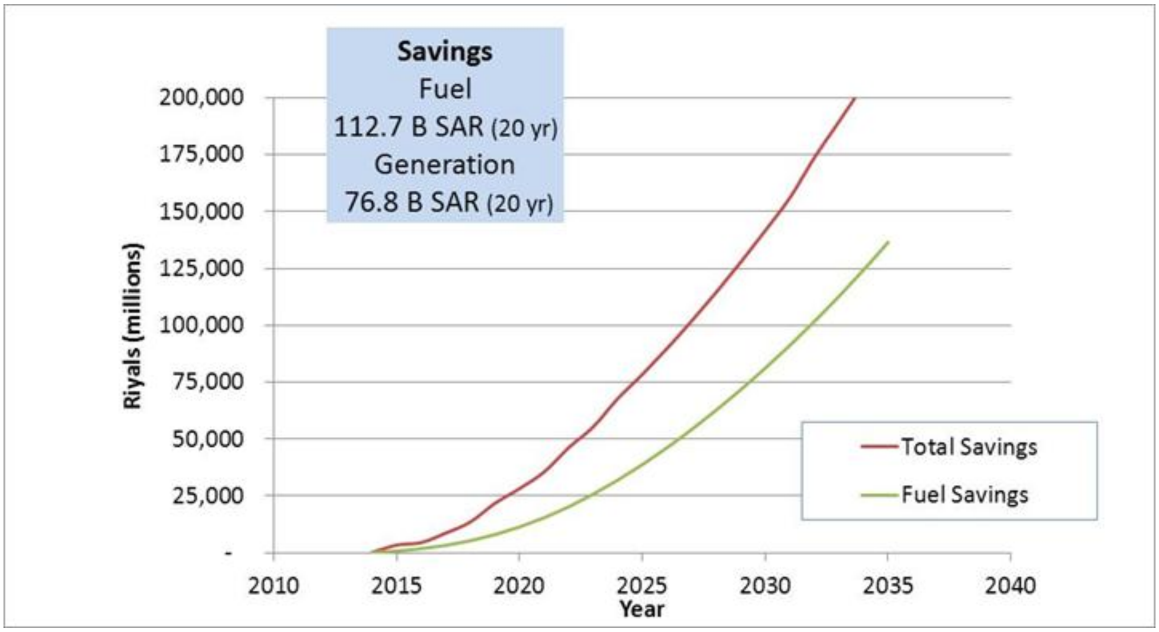


**Figure 1 Program Implementation Benefits**

### *2-2 Methodology*

As described in Zhou et al. 2012, different countries use different methods to set energy efficiency standards. The generalized criteria for the US, Japan, Australia, and the UE include significant energy savings through measures that are technologically feasible and have no excessive costs for consumers or manufacturers. Table 2 below shows the MEPS Standard Setting Analysis for five countries.

Table 2 MEPS Standard Setting Analysis

| | Analysis Overview | US MEPS | Australia MEPS | EU Ecodesign | Japan | China |
|---|---|---|---|---|---|---|
| *Screening Analysis* | screen potential product design options or efficiency levels | X | X | X | N/A | X |
| *Engineering Analysis* | evaluate and compare different design change or efficiency levels' effect on reducing energy use and cost | X | X | X | N/A | |
| *Energy and Water Use Analysis* | estimate operational energy and water for efficiency level | X | X | X | N/A | |
| *Mark-up Analysis* | convert consumer price to estimated manufacturer cost | X | X | | N/A | |
| *Life-cycle Cost and Payback Analysis* | evaluate life-cycle economic impact of potential standard level on end-users | X | X | X | N/A | |
| *Market Analysis* | evaluate efficiencies of current models in market | | X | X | X | X |
| *Shipment Analysis* | current and forecast shipment analysis | X | | X | X | |
| *National Impacts Analysis* | evaluate potential energy and economic impact on national level | X | X | X | N/A | |
| *Manufacturer Impact Analysis* | evaluates the impact on manufacturers' competitiveness, industry structure | X | X | X | N/A | |
| *Life-cycle Cost Subgroup Analysis* | evaluate disparity of impacts on specific consumer groups | X | X | X | N/A | |
| *Employment Impact Analysis* | evaluate net jobs created or eliminated | X | X | X | N/A | |
| *Utility Impact Analysis* | evaluate impact on national electricity and gas suppliers | X | X | | N/A | |
| *Regulatory Impact Analysis* | evaluate and compare impacts of non-regulatory alternatives | X | X | X | N/A | |
| *Environmental Assessment* | evaluate impact on $CO_2$, $SO_2$ and NOx emissions | X | Only $CO_2$ | Life-cycle env't impact | N/A | Only $CO_2$ |

With the exception of Japan, these countries and regions follow a specific set of analytical methods and tools in the process of setting MEPS and Ecodesign. Japan's standard-setting approach relies largely on the progress of innovation among a few large manufacturers. (Zhou et al. 2012). As a result it puts the smaller manufacturers at a disadvantage.

This study contained the following elements of the standard Laurence Berkeley National Laboratory analysis for US DOE and China (DOE 2011b, Fridley et al. 2001):

- Screening analysis
- Engineering analysis
- Energy analysis
- Mark-up analysis
- Life-cycle cost and payback analysis
- Market analysis
- Shipment estimation
- National impacts analysis
- Manufacturer impact analysis
- Utility impact analysis
- Environmental assessment

This study also added a grounding Reality Check by building and testing some lower cost modifications to Saudi Arabian baseline designs.

### *2-3 Purpose*

The purpose of this project was to encourage the production of air conditioners that effectively provide occupant comfort with a low power draw. For the Saudi climates, the appropriate metrics of performance are Sensible Capacity at T3, Sensible EER at T3, Total EER at T3, and Cycling Performance at T1 or T3.

### *2-4 Project Outcomes*

The Kingdom of Saudi Arabia Air Conditioner (KSASC) Project proved the viability of air conditioners designed to operate more efficiently in the Saudi climates. Laboratory testing proved that the new mini-split units can meet the objectives of the Project. The window units (room air conditioners aka. RAC) are more challenging, but the prior work of the manufacturers and the project confirmed that they can achieve at least a 15 percent energy savings.

The Project supplied information about problems with high temperature performance of R-407C including its high temperature performance and the lack of compressor availability in the sizes and types needed for the Kingdom.

The Project engaged air conditioner manufacturers in the process. This engagement produced increased dialogue between the manufacturers and the project team. This engagement was instrumental in tailoring the results to the capabilities of Saudi manufacturers.

### *2-5 Project Work Flow*

The first step in this project was to collect information about previous studies and about the requirements specified in the Saudi and foreign standards, and to use statistical questionnaires to obtain information from users, distributors and local manufacturers of air conditioning units and manufacturers of components of air conditioners regarding the most used types of air conditioners, and the level of the energy efficiency ratio available in the market, and the sale price of air conditioners on the user, and the average number of air conditioners in every home, and the average number of hours of operation a day. Also, and through the analysis of bills of electrical consumption provided by the Saudi Electricity Company, the team of the study obtained in depth usage information about the distribution of consumption classes over population in each region of the Kingdom. The information available from the U.S. Department of Energy about the chain of marketing of air conditioners from the factory until the user through the dealer and the seller was discussed. The team obtained indicators showing the cost of manufacturing. Also, research and information gathering has been made about the level of gas emissions in the Kingdom.

Based on the above information, the most produced, sold and used air conditioners have been determined. Also, the units of reference to represent those air conditioners in terms of type (window or mini-split) and cooling capacity was selected. Two reference units for window type conditioner with a capacity of 18,000 BTU / hour were selected, one of them with low energy efficiency ratio close to the value specified in the Saudi standard, the other with higher value. Also, two reference units of mini-split type conditioners with a capacity of 24,000 BTU / hour were selected, one of them with low energy efficiency ratio close to the value specified in the Saudi standard. These units were subjected to testing in a local certified laboratory to take their results as a benchmark to compare the results of test units and other units available in Saudi Arabia.

After test completion of the reference units, the work group of the study started conducting the process of development using simulation models with the program of American Oak Ridge National Laboratory - seventh mark (ORNL Mark VII). Hundreds of models have been operated to analyze the possible design modifications, individually and combined. The tested modifications in ORNL simulation include: increase of internal and external air flow, increase the density of the evaporator and condenser fins, increase of the areas of the heat exchangers, the interaction between internal and external improvements in heat exchanger and mini-tube heat exchanger and increasing of the number of rows of tube of heat exchanger and increasing the number of circuits of heat exchanger and the length of capillary tubes and the higher efficiency compressors and the size of the compressor and the compressors with refrigerant liquid.

Design modifications were implemented with one of the air conditioner factories in the Kingdom of Saudi Arabia to determine the possibility of implementation within the constraints of local manufacturing capabilities and the availability of the components and the cost considerations and the results of the long-term operation in the climates of the Kingdom of Saudi Arabia.

### *2-6 Conclusions*

1. Saudi Arabia needs air conditioners that do little or no dehumidification for the drier areas and air conditioners that do extensive dehumidification for humid areas. The test procedure should measure the two different types of performance and the minimum standards should be set for each area based on that performance.
2. The potential savings from upgrading window unit efficiency is very large due to the large number of units in the Kingdom, their frequent use, and their low efficiency. The savings are not large enough to attract the consumer to buy a more efficient unit, but the fuel and distribution savings are sufficiently attractive to warrant expenditures to accomplish the changeover and enforce the new standard. A short term incentive at the manufacturers' level would be helpful.
3. Window units have significant limitations due to the small size of the cabinet. As the capacity (tonnage) of a window unit increases the possibilities for high efficiency are diminished. Minimum efficiency standards for window units should vary with capacity.

4. Upgrading mini-split efficiency will produce savings sufficient to support expenditures to accomplish the changeover and enforce the new standard. A short term incentive at the manufacturers' level would be helpful.
5. A significant number of units for sale in the Kingdom do not meet SASO acceptance standards for true capacity and efficiency compared to labeled specifications. Enforcement of SASO standards by check testing and deliberate action is needed.
6. The manufacturers will have a challenge to maintain efficiencies as refrigerants 407C and 410A are introduced. Both refrigerants have lower efficiencies than the current R-22 refrigerant. The decrements are probably between 6% and 14% at 46°C.
7. Airflow through the air conditioners is lower than desirable. Low cost/no cost changes can be made to improve airflow and efficiency.
8. To avoid unnecessary air conditioner electrical consumption, the air conditioners should come with occupancy sensors that turn off the unit after the room is unoccupied for some time period.
9. Contrary to some existing literature, analysis of residential billing data indicates that the air conditioning accounts for less than 60% of the residential electrical usage and that it probably averages near 46% of the residential energy consumption. The percentages vary by region with the highest in the Eastern Region and the lowest in the Southern Region. The study estimates that 61% of the residential peak is air conditioning.
10. The current minimum efficiency standards for air conditioners in Saudi Arabia and minimal enforcement are a monetary drain on the Kingdom. Low standards, energy wasting buildings, and low electricity costs combine to make air conditioning very costly to the Kingdom.
11. While the current standard test procedures for window and mini-split units produce EER – a steady state test result, the units should be cycling. To properly assess and capture the potential energy savings in the field, a test procedure that more accurately represents field conditions would be preferable.
12. To be most effective at bringing air conditioning consumption down across the Kingdom will require field monitoring of how the air conditioners operate and their installed efficiencies. These data are likely to point to potential cost effective improvements.
13. Based on the average retail cost for the most common window and mini split units the total costs at the manufacturer are:
    - 24000 BTU Mini Splits 1230 SR (328 USD)
    - 18000 BTU Window Units 553 SR (147 USD)

### *2-7 Recommendations*

1. Provide a two year advance notice in changing the Minimum Standards for Air Conditioner Efficiency.
2. Finalize the method of enforcing the Standard in the first year. In the second year implement enforcement of the existing standard with random check testing and the opportunity for challenge testing.

3. Decertify and remove units from the market that fail check testing or challenge testing in the first and following years.
4. Fine the manufacturer for each decertified unit sold more than thirty days following decertification notification.
5. Focus the Standard on the most important conditions for the energy grid (T3 conditions 46°C outdoors)
6. Provide motivation within the standard for air conditioners that operate more efficiently under cycling conditions
    a. Provide a standard of test that includes cycling performance of the air conditioner
    b. Provide rating enhancements (points) for specific features that reduce energy use including: occupancy sensors with off time delays, condensate capture and evaporation cooling to the inside unit in dry climates.
7. Provide different standards for varying capacities and types of air conditioners according to the following schedule.

**Table 3 Recommended Minimum Standards**

| | Window AC | | Mini-Split |
|---|---|---|---|
| Minimum Standard | < 18,000 BTUh Capacity | 18,000 BTUh or Greater Capacity | All Capacities |
| 2014 (T1 EER) | 9.0 | 8.6 | 9.4 |
| (T3 EER) | 6.7 | 6.4 | 7.0 |
| 2016 Addition | Occupancy Sensor and Time Delay | Occupancy Sensor and Time Delay | Occupancy Sensor and Time Delay |
| 2018 Change | Cycling Test Standard with Sensible EER for Dry Regions | Cycling Test Standard with Sensible EER for Dry Regions | Cycling Test Standard with Sensible EER for Dry Regions |

8. Provide at least two years advanced notice for further increases in the test procedure as well as mandatory minimum Sensible and Total efficiencies
9. Provide necessary additional research, including:
    a. A field study of the actual conditions of the thermal envelope of existing Saudi residences
    b. A field study of available retrofits to improve the thermal envelope of existing Saudi residences
    c. A field study of the actual operating conditions (indoor temperatures and humidity as well as occupant control, watt draw, and delivered capacity) of window and split air conditioners in existing Saudi residences. This would include electronic monitoring of air conditioners in a wide range of Saudi residences for one year.
    d. An air conditioner development program to include alternatives outside the current capabilities of Saudi manufacturers including; heat exchanger types, higher air flow efficiency, higher airflow, condensate capture and reuse for dry climates, fan revisions, and higher efficiency motors.

e. Develop a standard method of test for dust degradation of air conditioner performance.
f. Develop a cycling test for window and Mini-Split air conditioners to be implemented in 2018.

10. Consider short term financial incentives at the manufacturer/importer level to mitigate potential market disruption. See Table 4.

**Table 4 Recommended Incentives**

| Time Period | Air Conditioner Refrigerant, Type, and Capacity | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Refrigerant R-22 | | | | Refrigerant R-410A or R-407C | | | |
| | Window AC | | Mini-Split AC | | Window AC | | Mini-Split AC | |
| | < 18,000 BTUh Capacity | 18,000 BTUh or Greater Capacity | <24,000 BTUh Capacity | 24,000 BTUh or Greater Capacity | < 18,000 BTUh Capacity | 18,000 BTUh or Greater Capacity | <24,000 BTUh Capacity | 24,000 BTUh or Greater Capacity |
| 2014 (US$) | 47.04 | 47.04 | 41.98 | 52.48 | 56.45 | 56.45 | 50.38 | 62.98 |
| SAR | 176 | 176 | 157 | 197 | 212 | 212 | 189 | 236 |
| 2016 (US$) | 47.04 | 47.04 | 41.98 | 52.48 | 56.45 | 56.45 | 50.38 | 62.98 |
| SAR | 176 | 176 | 157 | 197 | 212 | 212 | 189 | 236 |
| 2018 (US$) | 30.58 | 30.58 | 27.29 | 34.11 | 36.96 | 36.96 | 32.75 | 40.93 |
| SAR | 115 | 115 | 102 | 128 | 138 | 138 | 123 | 154 |

### *2-8 Benefits to Entities within the Kingdom*

Fundamentally slowing the growth of domestic oil consumption to provide electricity to air conditioners is beneficial to the electric utility and the oil company. The initial cost for air conditioners will rise and the customer energy cost savings over the lifetime of an average window unit will not cover the increased initial cost. For mini-split air conditioners the energy cost savings will cover the increased initial cost in about 8 years. For the oil company, the oil that would be burned for electricity generation can be reduced and that oil can be sold on the world market. The Kingdom will avoid the pollution associated with burning the oil. The effect on market share for different AC manufacturers is unknown but the change could cause market disruption. A portion of the increased revenue to the utility and/or oil company can be used to buy down the cost of higher efficiency air conditioners. If this incentive were delivered at the manufacturers' level, the manufacturers of air conditioners and their distribution chain would see no loss in net revenue and even a potential increase in sales.

## Chapter 3: Study Project.

### 3-1 Background and Overview

Air conditioners sold and operated in the Kingdom of Saudi Arabia (KSA) have efficiencies that are less than optimum from an overall benefit cost ratio. Saudi consumers are used to a heavily subsidized electrical tariff that results in little economic incentive to the consumer to conserve energy by purchasing a higher efficiency and more costly air conditioner.

Saudi air conditioners cannot be directly compared to those sold in countries such as the United States (US) that have seemingly higher standards than the current Saudi standard. The standard for split and package units in the US is based on tests with an outside temperature of 27.8°C (82°F). The test and calculation methodology provides an incentive for manufacturers to use variable speed compressors on mini-split units. In the US, the government and electric utilities provide monetary incentives for the purchase of higher efficiency machines because of the positive effect higher efficiency equipment has on reducing grid load and excessive energy consumption. In the US the consumer pays the full cost of the electric power consumed.

In the Kingdom of Saudi Arabia (KSA) and most of the world the standard of test is a steady state test that is not representative of how air conditioners should be operating for minimum energy consumption. In KSA there is a dual standard for air conditioner efficiency 7.5 at T1 (35°C Outside, 27°C dry bulb inside and 46.6% relative humidity) and 5.4 at T3 (46°C Outside, 29°C dry bulb inside and 38.2% relative humidity). In the Kingdom, high outdoor temperatures demand specific compressors designed to withstand the more difficult heat rejection (compressor cooling). This problem does not exist in many other countries.

Window units in all countries have significant limitations due to the small size of the cabinet they must fit. As the capacity (tonnage) of a window unit increases the possibilities for high efficiency are diminished. In order to deal with this, the US has decreasing efficiency standards for window units based on capacity. The highest efficiency window units sold in the United States have recently been removed from the market because check testing showed they did not meet their claimed efficiency.

### 3-2 Goals

The project will yield for Saudi Arabia new air conditioners using less energy, and will have less portion of the peak demand of summer compared to traditional air conditioners. Therefore, consumers will get energy savings. Consequently, power supply companies will spend less money in establishing infrastructure to meet the increasing demand on power in the electrical grid.

### 3-3 Project Objectives

1. To obtain information on the current state-of-affairs of air conditioners and national production capacity of air conditioners in Saudi Arabia;

2. To know the most air conditioners used in Saudi Arabia;
3. To conduct tests on samples of the most used products (as benchmarking units) so that their results would be the basis to compare for developing the design suitable for hot climate;
4. To indicate the minimum allowable EER to realize maximum limit of optimal prospective lifecycle that achieves the consumer's interest;
5. To reach optimal air conditioner design methodology at low lifecycle cost. This design methodology covers split and window units. The study will strive to make the newly designed air conditioners cost-effective. The new designs are expected to offer lower cost in the lifecycle (consumption, maintenance, prospective life)in the kingdom's climatic conditions;
6. To prove potentiality of lowering peak power demand for the hot climate. The new designs are expected to offer decreases in the necessary peak power demand ranging between 15% and 25% as well as 10%-20% energy consumption savings;
7. The project's research and studies process will comprise system design methodology assisted by computer simulation to direct development of the prototype, and improve components performance and lifecycle cost;
8. Optimal designs will be developed using repetition process. Two air conditioner prototypes shall be built and tested; one will be mini-split and the other will be window type, so that they will be optimal for use in hot climate with regard to performance, power consumption and lifecycle, together with controls to provide optimal cooling in dry and humid conditions;
9. To build a mini split air conditioner and another window air conditioner that consume lower power at peak time, and improve their life cycle costs within the current available or reasonably available manufacturing capabilities. This unit shall be able to:
    a. Reduce the demand for the energy (designated for these air conditioners) at a percentage ranging between 10% and 25% at high ambient temperatures;
    b. Reduce electric operation cost for this unit (energy consumption) at a percentage ranging between 10% and 25%
    c. Maintain lifecycle cost and maintenance costs equal or less than the benchmarking units (the samples previously tested according to Objective 3)
    d. Maintain user convenience under seasonal domestic environment different from the design environment
    e. Seek that the increase in provisional costs ranges between 5% and 25% above the reference units in accordance with features.
10. The study results will also contribute to introducing the suitable modifications to Saudi Standards upon updating them by the Saudi Arabian Standards Organization (SASO). The results will be available to the Technical Committees (TCs) concerned with the Standards based on the project results. The study TCs with the technical information necessary to introduce the proposed modifications to the standards, to obtain requirements for "low electricity consumption air

conditioners", and requirements for lifecycle cost improvement for such new-design air conditioners

11. Achievement of these objectives will be evaluated at project end by submittal of written documents containing data and analysis supporting specific results
12. Secondary objectives include: building partnerships with manufacturers to exchange information on project results, test benchmarking and new units and urge them to care more for marketing of higher efficiency air conditioning products.

## *3-4 Project Work Flow*

### 3-4-1 Initial Data Collection

#### *3-4-1-1 Suitable EER for the Kingdom of Saudi Arabia*

The current minimum efficiency standards for air conditioners in Saudi Arabia as well as the ineffectiveness of standards enforcement is a monetary drain on the Kingdom. Low standards combined with energy wasting buildings and low electricity costs combine to make air conditioning in the Kingdom very costly and cost ineffective. Higher efficiency air conditioners that provide the following characteristics would be highly cost effective:

1. They would provide the type of conditioning necessary (cooling or cooling and dehumidification) for the local climate.
2. They would provide controls that reduce air conditioner operation when the conditioned space is not occupied.
3. They would provide higher efficiencies that are more cost effective when viewed from the Kingdom have overall cost perspective.

This study initially obtained opinions about the suitable EER for Saudi Arabia. The opinions varied by the positions of the respondents and covered the range from the current minimums to 16 EER. These opinions showed a wide range of understanding of the challenges, test procedures, and differences between various types and sizes of air conditioners. The respondents to the survey were all stakeholders in the process. Seventy three percent of the respondents considered the current standards low or very low, twenty percent considered them reasonable, and seven percent considered them high or very high.

While the current standard test procedures for window and mini-split units produce EER – a steady state test result, the units should be cycling. To properly access and capture the potential energy savings in the field, a test procedure that more accurately represents field conditions would be preferable.

#### *3-4-1-2 Fan Off Delay and Sensible EER*

A large portion of the Kingdom is hot and dry with no need for dehumidification. In these locations the need is to reduce the temperature of the air inside the occupied space (which is called Sensible Cooling). Nevertheless, air conditioners across the whole country dehumidify, producing moisture condensate. The amount of energy going into producing condensate is a waste of energy in the dry portions of the Kingdom. Figure 2 shows the difference between the Total EER (which includes dehumidification) and Sensible EER that includes only the cooling useful in dry climates. This figure shows the average performance of the four baseline units in the laboratory tests.

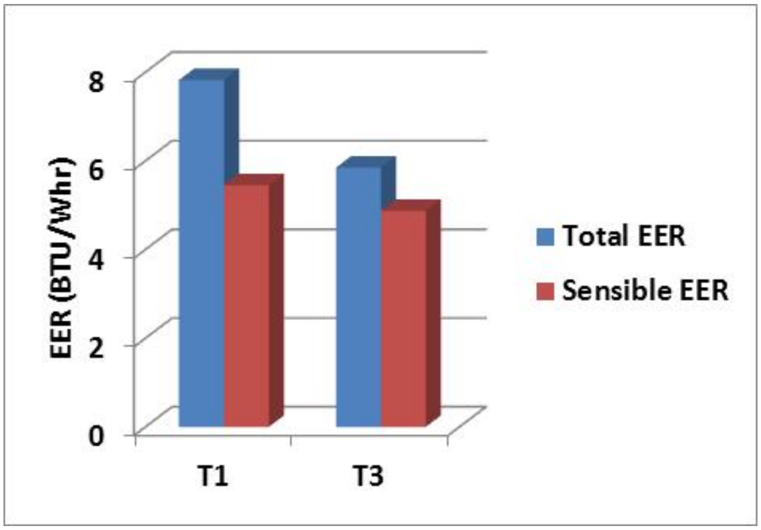


Figure 2 Sensible and Total EER at T1 and T3

It is notable that 30% of the work air conditioners are doing at T1 is wasted in dry conditions.

There are two known available methods of reducing this waste and providing more sensible cooling for the same expenditure of electricity. One method is increasing the airflow across the inside coil (evaporator). The second method is to run the inside coil fan after the compressor shuts off to evaporate the moisture on the coil producing sensible cooling and delivering it to the conditioned space. This process is very effective as shown in Figure 3 . This figure is for one of the baseline units in the laboratory test.

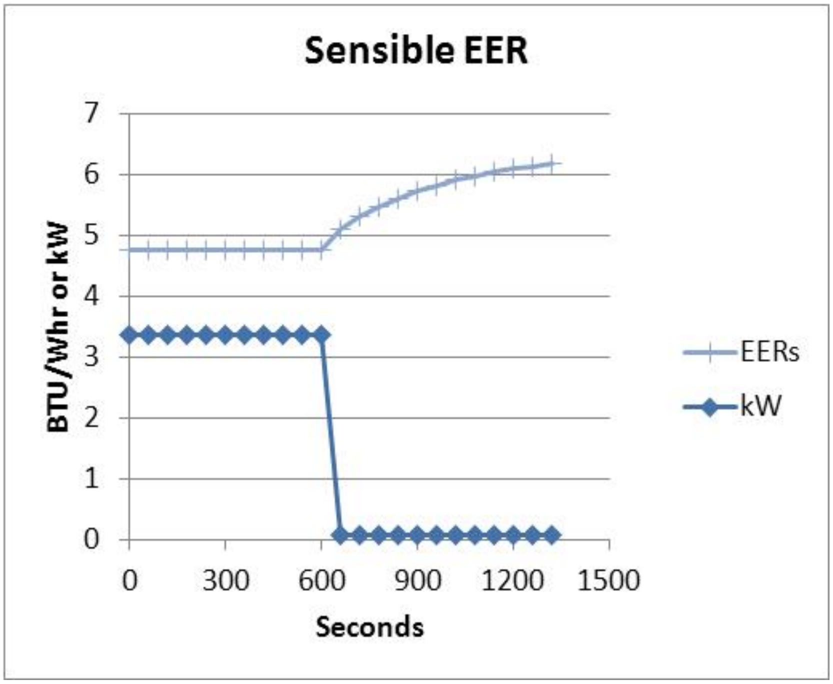


**Figure 3 Fan Off Time Delay – Sensible Efficiency Improvement**

It is notable that the Sensible EER increased by 29% when fan operation was extended. The length of the fan run at the end of the cycle is limited by the amount of moisture on the coil and by the fan electrical consumption as well as fan heat delivered to the conditioned space. For these reasons a continuous fan is a bad idea.

#### *3-4-1-3 Methods of Standards Enforcement*

Without firm enforcement of the efficiency standards the market will be distorted by the presence of low cost inefficient units. This pressure lowers the complying manufacturers' motivation to provide high quality high efficiency air conditioners. The initial survey addressed this issue and found that 97% of the stakeholder respondents agreed that testing a random sample of air conditioners from the marketplace was an effective enforcement mechanism. They supported testing by an independent entity or by the government.

This study recommends a procedure that includes the following:

1. Units must be randomly sampled from the marketplace across the Kingdom. At least one unit per each family of models must be tested.
2. Manufacturer is invited to observe the check test at the independent laboratory.
3. If the unit meets or exceeds the minimum standard as defined by SASO, the manufacturer can continue to sell the units in Saudi Arabia and receive any applicable incentive payments for units sold within the Kingdom.

4. If the first check unit fails, another unit of the same model is sampled from the marketplace. The manufacturer is responsible for the costs of the second sampling and test.
5. If the second unit meets or exceeds the minimum standard as defined by SASO, the manufacturer can continue to sell the units in Saudi Arabia and receive any applicable incentive payments for units sold within the Kingdom.
6. If the second check unit fails the manufacturer is no longer authorized to sell that model in the Kingdom and will be fined for each unit sold more than 30 days after notification of the second failure. The manufacturer has the opportunity to remove all units in that family of models from the market, or if they decide to continue to sell other units from that family, the process will repeat with a first sample of a different model in that family.

The same process will take place for units that are challenged by a competitor or other interested party. The cost of the sampling and testing of the first unit will be paid by the challenger if the unit meets or exceeds the standard. The cost of the sampling and testing of the first unit will be paid by the manufacturer if the unit fails to meet the applicable standard.

### 3-4-2 Literature Survey

This section is omitted in US English version of report.

### 3-4-3 Residential AC Data

It is commonly stated that 60% to 70% of the energy in buildings in Saudi Arabia is consumed by air conditioning. (Said, Habib & Iqbal 2003, Al-Qahtani 2011, MOWE 2010, Chang 2011) The following analysis indicates that the air conditioning accounts for less than 60% of the residential electrical usage and that it probably averages near 46% of the residential energy consumption. The percentages vary by region with the highest in the Eastern Region and the lowest in the Southern Region. Derivations of these statistics are described in the Bottom up Estimate from Billing Data subsection below. The analysis estimates that about 61% of the peak electrical use in the Kingdom is due to air conditioning.

#### *3-4-3-1 Unit Size, Type, and Number*

The team examined existing estimates of the size, type, and number of residential air conditioners in the Kingdom.

Saudi Manufacturers estimate that the number of window air conditioners in the Kingdom is in excess of 10 million units with a replacement rate of over 1 million units a year. The market size is 2 million ACs per year (Upadhyay 2011).

Phase one of this study included an onsite survey of 600 residences in Jeddah, Riyadh, Qassim, Dammam, Abha, Hail, and Jizan. The most common window unit found in the survey was 18,000 BTU and the most common Mini-split was 24,000 BTU.

The survey found the air conditioner statistics shown in Table 5.

**Table 5 Unit Size, Type and Number per Household**

| Region | Central | Western | Eastern | South |
|---|---|---|---|---|
| Median number of ACs | 4 | 4 | 5 | 3 |
| % Window Units | 61% | 83% | 71% | 53% |
| % Split Units | 39% | 17% | 29% | 47% |
| Average Window Tonnage | 1.6 | 1.3 | 1.6 | 1.4 |
| Average Split Tonnage | 1.9 | 1.6 | 2 | 1.6 |
| Total Tonnage | 6.87 | 5.40 | 8.58 | 4.48 |

These estimates correspond to a total of 13,315,000 residential window air conditioners in Saudi Arabia. These estimates provide one of the scenarios for the economic analysis in this study.

#### *3-4-3-2 Unit Lifetime*

The survey conducted during this study found a customer reported air conditioner replacement schedule what would produce 82.7% replacement by the end of year 10. This is considered unrealistic. The manufacturers' estimate is that the average replacement occurs after year 10. For this analysis we have estimated the average lifetime of a window air conditioner at 10 years and the average lifetime of a mini split at 15 years.

The assumed survival rates of the window and split air conditioners are shown in Figure 4.

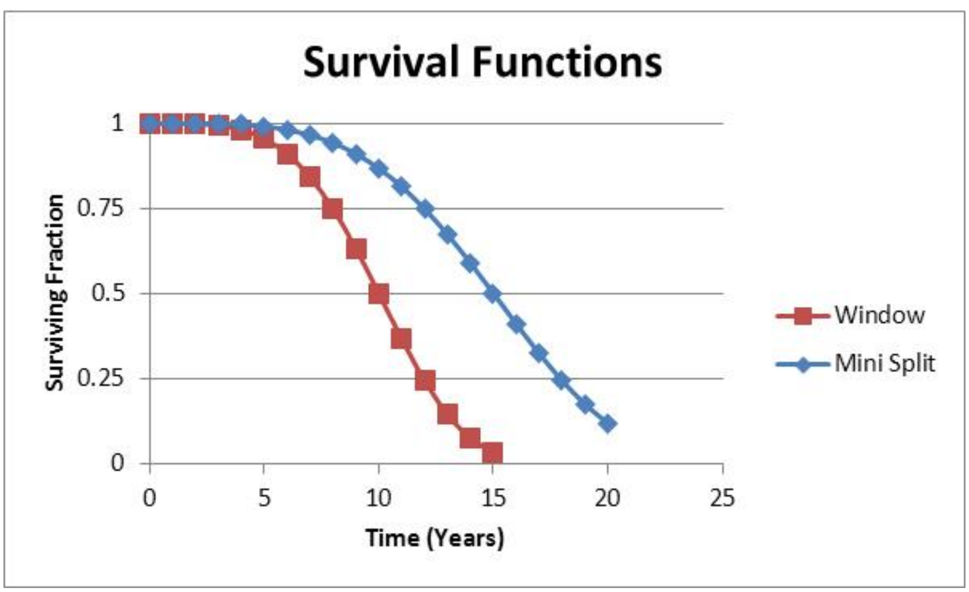


**Figure 4 Window and Mini Split Survival Functions**

### *3-4-3-3 Manufactured Efficiency Check Testing*

Five units (three window units and two mini-splits) from four manufacturers were check tested at Ikhtebar, a certified test facility in Dammam. These units are required to meet SASO Standard 2663 which includes the following criteria:

- Tested effective power input $\leq$1.10 x rated power.
- Tested cooling and heating capacity $\geq$0.95 x rated capacity.
- Tested EER $\geq$0.95 x rated EER.

The results are shown in Figure 5.

One of the units (E1) failed to perform within specifications with respect to:

- T1 and T3 EER
- T1 and T3 Capacity

A second unit (E2) was obtained from the manufacturer of the failing unit and tested at the same facility. The second unit produced 95.6% of its labeled capacity at T1. That unit failed to meet the standard since it produced only 90.62% of its rated capacity and efficiency at T3.

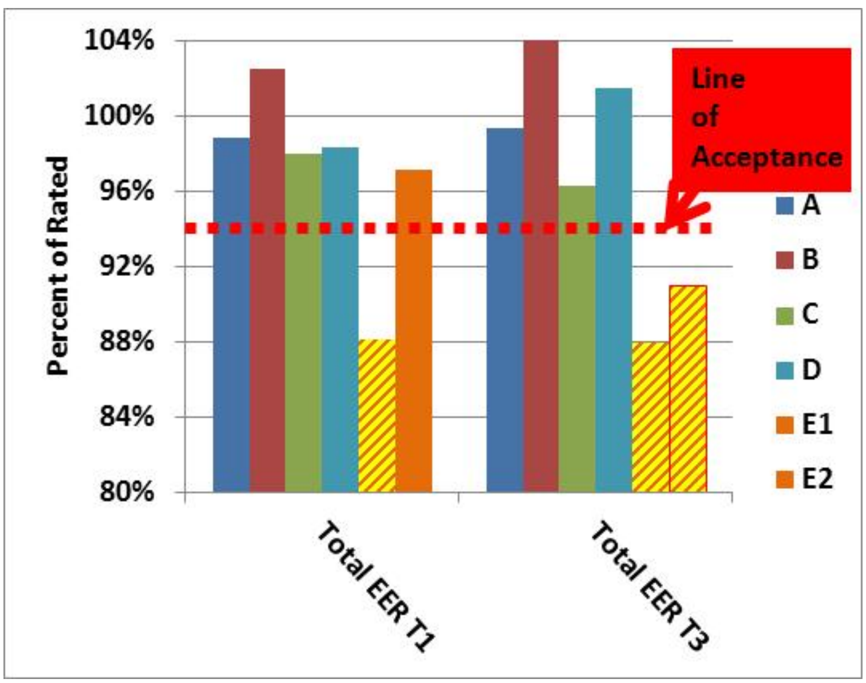


Figure 5 Laboratory Tests of Check Units from Saudi Marketplace

### *3-4-3-4 Installed Efficiency*

Very little is known about the installed efficiency of residential air conditioners in KSA. Antidotal information suggests that performance of air conditioners is degraded by large collections of dust on the outside and inside coils of the air conditioners. There appears to be no field study of common dust accumulation and performance degradation in the Kingdom. Antidotal information also suggests that at least half of the mini-split air conditioners are installed by non-professionals and that air is not evacuated from the lines and indoor coil prior to releasing the refrigerant into the AC circuit. The inclusion of air (a non-condensable at operating pressures) in the system degrades the performance of air conditioners.

All of the above items will make the air conditioners less efficient than their rated efficiencies.

#### *3-4-3-5 AC Operating Modes*

Antidotal information also suggests that many customers set their window unit thermostats to the highest setting and often run the air conditioners continuously whether or not the room is occupied.

The energy consumption of air conditioners is very dependent on how they are operated. Table 6 outlines the three primary operating modes of the air conditioners, a number of potential improvements to Saudi air conditioners, and the energy consumption effect of these improvements as they apply to the operating modes.

The three modes of operation are: Thermostat Controlled, On/Off by Occupant Adjustment (usually occurs when the thermostat control is set to maximum for a portion of the day), and Continuous On for all or major portions of the day. All three modes are present in all populations. The proportion of these operations in Saudi residential air conditioning is unknown.

**Table 6 Operating Modes, Efficiency Improvements, and Savings Potential**

| | Operating Mode | | |
|---|---|---|---|
| Efficiency Improvements | Thermostat Controlled | On/Off | Continuous On |
| Increase EER | Savings | Savings | Savings |
| Reduce Capacity | No Savings | Savings | Savings |
| Increase Capacity | No Savings | Increased Use | Increased Use |
| Occupancy Sensor | Some Savings | Large Savings | Large Savings |
| Fan Time Delay | Dry Climate Savings | Small Savings | No Savings |
| Occupancy + Fan Delay | Dry Climate Savings | Dry Climate Savings | Dry Climate Savings |

It is evident from the above table that care should be taken to not encourage the customer to install a large air conditioner. Maximizing the effectiveness of an intervention into the marketplace is likely to contain all of the above efficiency improvements while maintaining the same installed air conditioner capacity.

#### *3-4-3-6 Unit Average Consumption*

The energy consumption of residential air conditioners can be estimated from multiple methods. The most common method is “Top Down”. That method looks at the aggregate energy consumption of the utility or utility service area. The level of detail varies from annual, to monthly, to daily, to hourly data. A second method is “Bottom Up”. This method uses data from the individual unit, either the air conditioner, if available, or the household. This data is then aggregated up to higher levels. This study used both methods.

Table 7 displays the results from the three Top Down methods detailed in Appendix A along with the Bottom Up (Billing Data) method detailed below.

**Table 7 Air Conditioner Loads and Consumption by Multiple Analysis Methods**

| Analysis | Air Conditioner Peak Load (% of Peak) | Air Conditioning GWh (% of Total Saudi Consumption) | Residential AC Peak Load (% of Peak) | Residential AC GWh (% of Total Residential Consumption) |
|---|---|---|---|---|
| Monthly Peak Load | 43% | | 29% | |
| Load Duration | 61% | 42% | 41% | 54% |
| Load vs. Temp | 39% | | 26% | |
| Billing Data | | | | 46% |

The analysis in this study investigates three levels of residential AC energy consumption as a percentage of residential annual energy use: billing based 46%, medium 50%, and high 54%.

Residential peak AC load is estimated as 61% of the Residential peak load and 41% of the Kingdom peak load.

### *3-4-3-7 Bottom Up Estimate from Billing Data*

The research team requested random samples of monthly residential metered electrical consumption. The following data sets were analyzed for a bottom up estimate of residential air conditioner use.

**Table 8 Number of Units in the Sample**

| Location | 60 Amp | 100 Amp | 150 Amp | 200 Amp |
|---|---|---|---|---|
| Qassim 1 | 861 | 763 | 18 | 25 |
| Qassim 2 | 701 | 1014 | 46 | 21 |
| Jeddah | 8774 | 2875 | 152 | 747 |
| Hael | 512 | 1130 | 181 | 7 |
| Riyadh N | 239 | 1472 | 117 | 172 |
| Riyadh S | 81 | 1839 | 39 | 41 |
| Riyadh E | 114 | 1748 | 52 | 86 |
| Riyadh W | 29 | 1589 | 54 | 328 |
| Dammam | 1006 | 1991 | 1008 | 995 |
| Abha | 2431 | 466 | 8 | 12 |

Using site specific energy consumption data, bottom up estimates can be derived by disaggregation. Hael provides the most graphic example of this disaggregation. The 60 Amp service customers in Hael have an average baseline energy use of about 1,450 kWh per month. In the summer months the cooling energy use is added to the baseline, peaking in July with approximately 2,190 kWh for a total of 3,640. For these customers, the cooling consumption totals about 10,100 kWh in the sampled year. The cooling usage was 35% of their total annual use and 60% of their use in July.

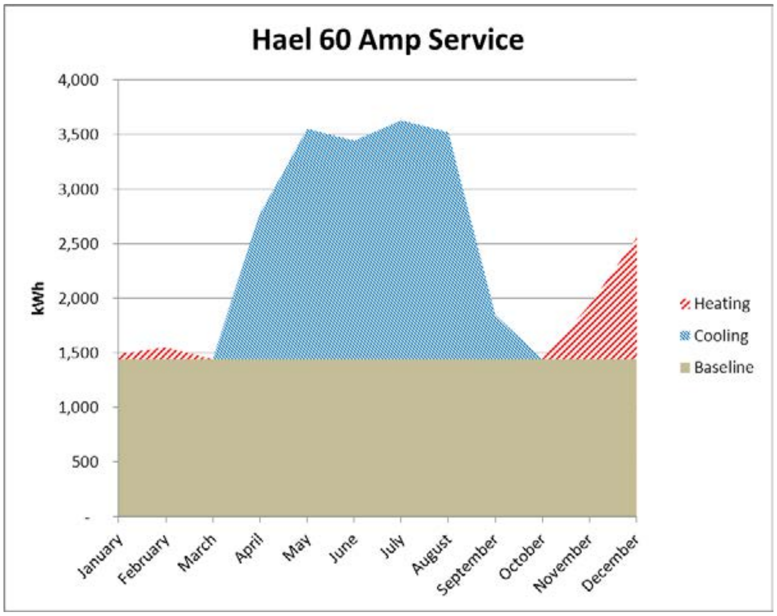


Figure 6 Monthly kWh Disaggregation Example -- Hael

These results are obviously driven by the local weather in the year. Hael has both hot weather exceeding 25°C and cold weather less than 12°C in the average year.

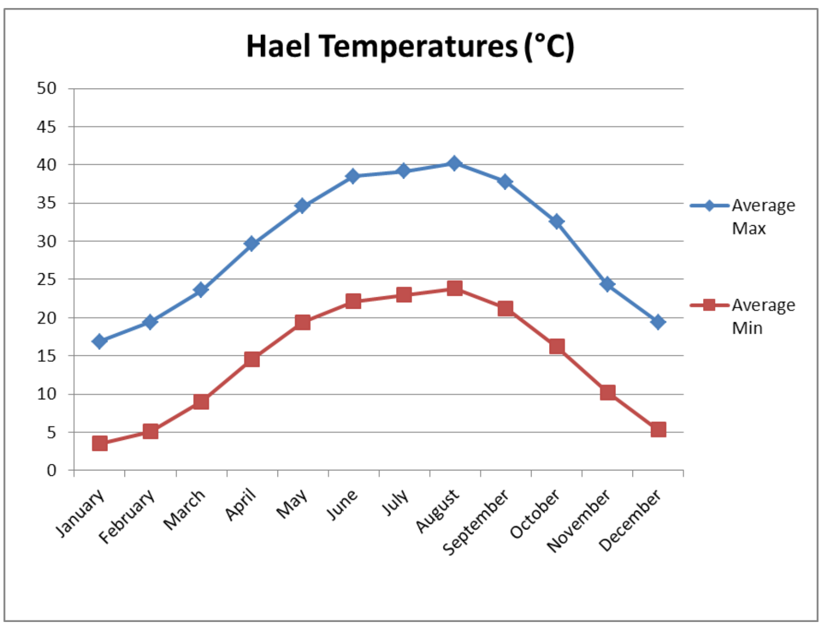


Figure 7 Hael Temperatures by Month

The results from this analysis are shown in the table below.

Table 9 Cooling Energy Consumption Detail from Sampled Billing Data

| Location | | 60 Amps | 100 Amps | 150 Amps | 200 Amps | Loc. Avg. |
|---|---|---|---|---|---|---|
| Qassim Central Region | Baseline monthly kWh | 959 | 1,331 | 1,395 | 2,254 | 1,176 |
| | Cooling annual kWh | 11,033 | 15,324 | 14,035 | 20,761 | 13,429 |
| | Cooling % of Total | 47% | 47% | 44% | 41% | 47% |
| | Cooling % of Peak Month | 69% | 69% | 66% | 67% | 69% |
| | n | 1,562 | 1,777 | 64 | 46 | |
| Jeddah Western Region | Baseline monthly kWh | 1,195 | 1,578 | 1,665 | 2,731 | 1,380 |
| | Cooling annual kWh | 9,312 | 12,052 | 15,222 | 22,118 | 10,774 |
| | Cooling % of Total | 39% | 39% | 43% | 40% | 39% |
| | Cooling % of Peak Month | 58% | 58% | 58% | 60% | 58% |
| | n | 8,774 | 2,875 | 152 | 747 | |
| Hael Central Region | Baseline monthly kWh | 1,445 | 1,739 | 2,093 | sSample | 1,692 |
| | Cooling annual kWh | 10,107 | 13,242 | 15,446 | sSample | 12,580 |
| | Cooling % of Total | 35% | 36% | 35% | sSample | 35% |
| | Cooling % of Peak Month | 60% | 63% | 62% | sSample | 62% |
| | n | 512 | 1,130 | 181 | 7 | |
| Riyadh Central Region | Baseline monthly kWh | 1,074 | 1,476 | 2,411 | 2,630 | 1,573 |
| | Cooling annual kWh | 12,362 | 17,841 | 23,621 | 30,137 | 18,677 |
| | Cooling % of Total | 49% | 49% | 45% | 48% | 49% |
| | Cooling % of Peak Month | 68% | 70% | 64% | 69% | 69% |
| | n | 463 | 6,648 | 262 | 627 | |
| Dammam Eastern Region | Baseline monthly kWh | 627 | 913 | 1,214 | 1,601 | 1,053 |
| | Cooling annual kWh | 16,055 | 22,736 | 26,871 | 34,451 | 24,557 |
| | Cooling % of Total | 68% | 67% | 65% | 64% | 66% |
| | Cooling % of Peak Month | 83% | 83% | 81% | 82% | 82% |
| | n | 1,006 | 1,991 | 1,008 | 995 | |
| Abha South Region | Baseline monthly kWh | 494 | 1,238 | sSample | sSample | 614 |
| | Cooling annual kWh | 473 | 1,830 | sSample | sSample | 692 |
| | Cooling % of Total | 7% | 10% | sSample | sSample | 7% |
| | Cooling % of Peak Month | 24% | 30% | sSample | sSample | 25% |
| | n | 2,431 | 466 | 8 | 12 | |
| sSample = Sample too small | | | | | | |

Assuming that these data sets are representative of residential customers in the regions, only the Central Region requires weighting. The three central region areas are weighted by population: Riyadh 78.9%, Qassim 14.15%, and Hael 6.95%

The team noticed that the reported total electricity sold to residences in the four regions in 2009 (Page 60 MOWE 2009) was not based on an aggregation of metered data from each region, but rather the product of the number of customers in the region and the Kingdom wide average residential use. Assuming that the total residential energy use (Page 60 MOWE 2009) is based on metered data for all residential customers, the results from this study's billing data sample was scaled by 73.9% to equal the MOWE reported total. The results are shown in the table below.

**Table 10 Cooling Energy Consumption Summary from Sampled Billing Data**

| Region | Central | Western | Eastern | South | Total |
|---|---|---|---|---|---|
| Residential Customers | 1,397,957 | 1,854,109 | 752,310 | 671,178 | 4,675,554 |
| Average Annual Cooling kWh | 12,946 | 7,966 | 18,156 | 511 | 10,024 |
| Total Cooling GWh | 18,098 | 14,769 | 13,659 | 343 | 46,869 |
| Average Total kWh | 27,127 | 20,236 | 27,337 | 7,188 | 21,566 |
| Total GWh | 37,922 | 37,520 | 20,566 | 4,824 | 100,832 |
| AC Percent of Total Residential Consumption | 48% | 39% | 66% | 7% | 46% |

#### *3-4-3-8 Deriving the Average Annual Consumption per Air Conditioner*

The Average Annual kWh per Residential Customer in Table 10 above is combined with the survey tonnage data in Table 5 in the following manner:

$$kWh\ Per\ Window\ Unit = \frac{Avg.Cooling\ kWh \times Avg\ Window\ Tonnage}{Total\ Tonnage}$$

$$kWh\ Per\ Split\ Unit = \frac{Avg.Cooling\ kWh \times Avg\ Split\ Tonnage}{Total\ Tonnage}$$

The estimated unit average consumption by region is shown in T**able** 11.

**Table 11 Scenario A Annual Energy Consumption per Air Conditioner by Region**

| Region | Central | Western | Eastern | Southern |
|---|---|---|---|---|
| Window kWh | 3016 | 1916 | 3386 | 160 |
| Split kWh | 3581 | 2359 | 4232 | 182 |
| | | | | |

#### *3-4-3-9 Alternative Scenarios – Residential AC Consumption at 50% and 54% of Residential Consumption*

Scaling the results from the 46% AC consumption shown in Table 11 by 0.50/0.46 and by 0.54/0.46 produces the Alternative Annual Energy Consumption by Region shown in **Table** 12 and **Table** 13.

Table 12 Scenario B -- Higher Use Estimate Annual Energy Consumption per Air Conditioner by Region

| Region | Central | Western | Eastern | Southern |
|---|---|---|---|---|
| Window kWh | 3278 | 2083 | 3680 | 173 |
| Split kWh | 3893 | 2564 | 4600 | 198 |

Table 13 Scenario C -- Highest Use Estimate Annual Energy Consumption per Air Conditioner by Region

| Region | Central | Western | Eastern | Southern |
|---|---|---|---|---|
| Window kWh | 3540 | 2250 | 3975 | 187 |
| Split kWh | 4204 | 2769 | 4968 | 214 |

### 3-4-4 Costs and Prices

#### *3-4-4-1Retail AC Prices*

Phase one of this study included a survey of retail AC outlets to obtain data on the retail prices of air conditioners in the Kingdom. The average prices by capacity are shown in Figure 8. The average price for the most common size Mini Split unit (24,000 BTU) was 2756 Saudi Reals (735 USD). The average price for the most common Window unit (18,000 BTU) was 1238 SR (330 USD).

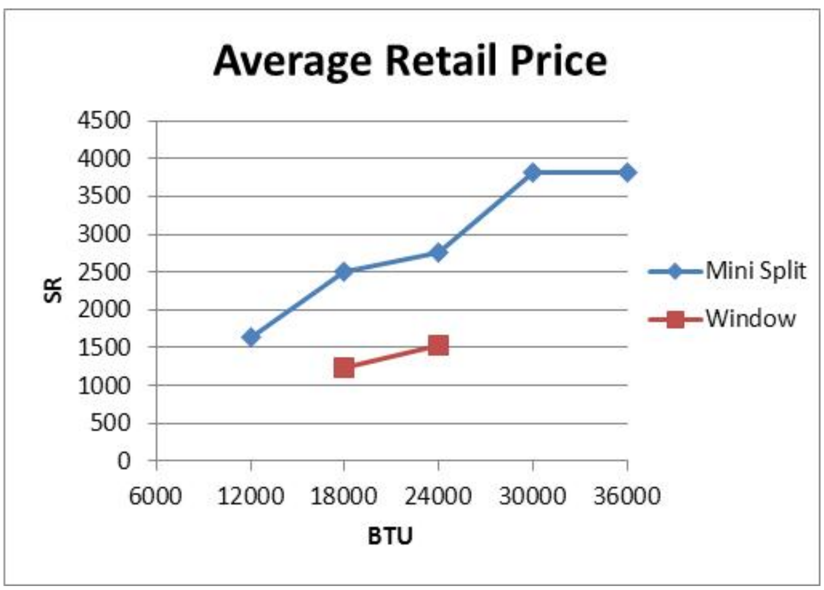


Figure 8 Average AC Equipment Cost

#### *3-4-4-2 Estimate and Derivation of Distribution Chain Multiplier*

The ratio between the consumer cost and the manufacturer cost is the distribution chain multiplier. This factor accounts for the markup of the cost of the air conditioner at the manufacturer's level. The factor accounts for overheard costs, research and development, depreciation, transportation, etc. that are not in the materials and labor costs of the manufacturer. This factor also accounts for the markup in the rest of the distribution chain including the retailer.

Information was not made available to the team concerning the markups in the Saudi marketing chain, so the distribution multiplier was derived from available sources: the distribution multipliers in the United States estimated by DOE for split and window air conditioners.

For a distribution chain that includes:

Manufacturer ⟹ Distributor ⟹ Dealer ⟹ Customer

The US Data (DOE 2011, 2002) show the representative markups listed in Table 14.

**Table 14 Distribution Chain Markups**

| | Type | |
|---|---|---|
| Actor | Split | Window |
| Manufacturer | 1.29 | 1.26 |
| Distributor | 1.37 | 1.37* |
| Equipment | 1.27 | 1.45 |
| Total Markup | 2.24 | 2.50 |

* DOE analysis does not have a distributor in the chain. Distributor markup from Split Units is used.

This analysis is using an estimated 2.24 distribution chain multiplier.

#### *3-4-4-3 Total Cost at the Manufacturer*

The total cost at the manufacturer is given in Equation 1:

**Equation 1**

$$MC_{total} = RP/MU_{total\ chain}$$

Where:

$$MC_{total} = Manufacturer's\ Total\ Cost$$

$RP = Retail\ Price$

$MU_{total\ chain} = Markup\ for\ Total\ Chain$

Based on the average retail cost for the most common window and mini split units the total costs at the manufacturer for the most common units are:

- 24000 BTU Mini Splits 1230 SR (328 USD)

- 18000 BTU Window Units 553 SR (147 USD)

#### *3-4-4-4 Component Costs at the Manufacturer*

Five sources are analyzed to estimate costs at the manufacturer:

- Survey responses from KSA manufacturers
- US DOE Direct Final Rule Technical Support Documents for Room Air Conditioners
- US DOE Direct Final Rule Technical Support Documents for Residential Central Air Conditioners and Heat Pumps
- Retail Prices for replacement parts
- Survey responses from KSA retailers for assembled unit prices

All the source data are configured as percentages of the total cost at the manufacturer.

##### 3-4-4-4-1 KSA Manufacturer Survey

This survey provided an anchor for the final results on critical components including the compressor. KSA manufacturers' data are confidential. Data from KSA manufacturers was limited and data from outside the Kingdom (U.S, and China) were used to supplement the information.

The most expensive single item in the assembly is the compressor. From the current baseline, the KSA manufacturer survey indicates a 10% increase in compressor EER will increase the compressor cost by 20%.

##### 3-4-4-4-2 US DOE Estimates and Estimates from Replacement Parts

**Table 15 Estimated Component Costs**

| | Window AC | | Split AC |
|---|---|---|---|
| Component | US DOE | Replacement Parts Based Estimate | US DOE |
| Compressor | 28% | 30% | 29% |
| Motor and Fans | 10% | 12% | 17%* |
| Condenser Coil | 7% | 8% | 12% |
| Evaporator Coil | 5% | 8% | 7% |
| Controls | 11% | | |
| Other Materials | 19% | | 19% |
| Labor | 19% | | 16% |

US Department of Energy sources are the Direct Final Rule Technical Support Documents for the Energy Conservation Standards for Room Air Conditioners, and for Residential Central Air Conditioners and Heat Pumps (DOE 2011b, 2011c).

#### *3-4-4-5 Electricity Cost to the Consumer*

Air conditioners are the cause of peak and responsible for the increases in energy consumption at the marginal tariff rate (the highest rate for an individual residential customer). According to MOWE (2009A) the breakdown of residential customers by tariff rate is shown in Figure 9. The residential tariff rate is plotted in the same figure (ECRA 2011).

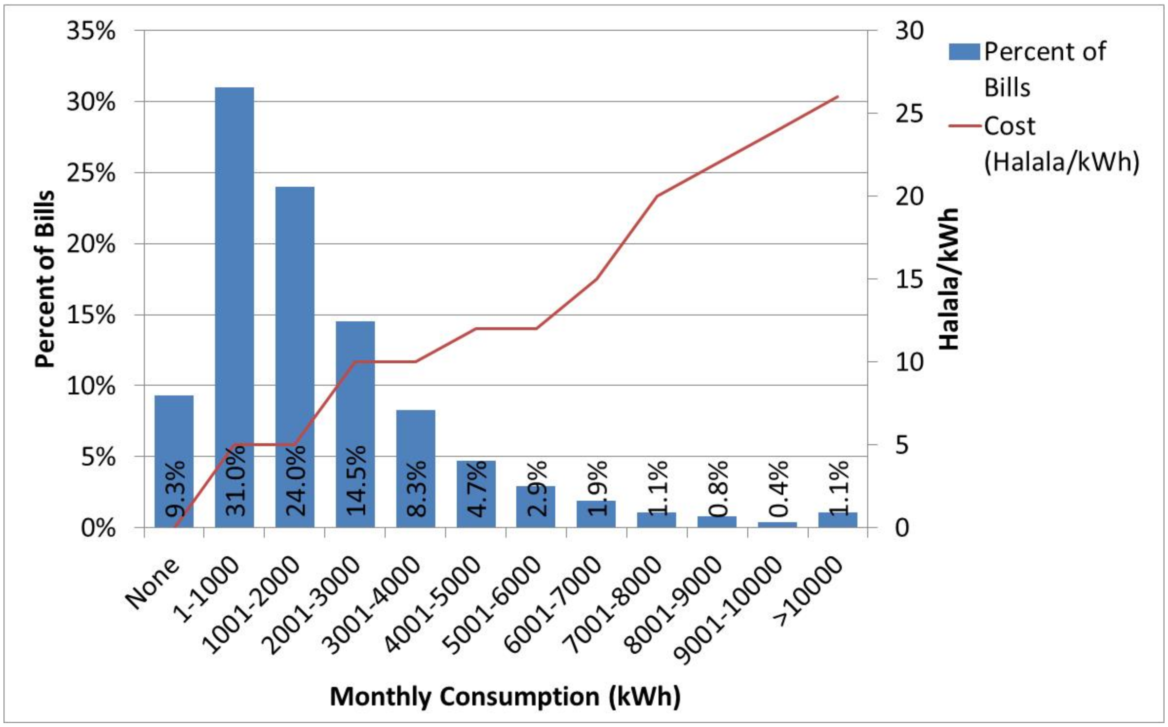


**Figure 9 Monthly Electricity Consumption and Costs**

Over the year more than 50% of the bills are at 5 Halala/kWh. The billing analysis in this study found the average cost per kWh by month shown in Figure 10.

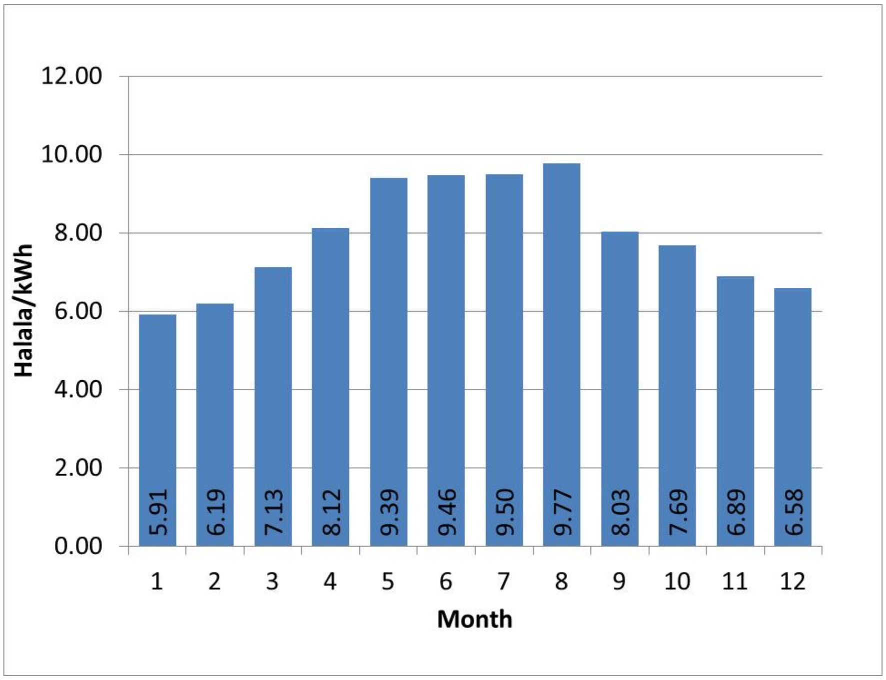


**Figure 10 Average Cost per kWh by Month**

In the hottest months the average residential cost per kWh is between 9 and 10 Halala. The analysis in this study assumes the average residential air conditioning kWh costs the customer 9.5 Halala (2.53 US cents). This is substantially less than the 4.0 US cents in the Aramco estimate shown in Figure 11.

#### *3-4-4-6 Electricity Cost to the Kingdom*

Electricity costs are highly subsidized in the KSA. A Saudi Aramco estimate of the cost of KSA electricity is shown in Figure 11 (Al-Qahani 2011).


**Figure 11 Electricity Subsidy in Saudi Arabia in US Cents per kWh**

Saudi Aramco estimated the cost to the kingdom of 45 Halala (12 U.S. cents) per kWh with 27 Halala (7.2 U.S. cents) in fuel costs at market prices.

Bain and Company produced three estimates of fuel costs based on three different values for a barrel of oil (J. Rahi, personal communication, August 28, 2012). These values were:

- At 150 Saudi Riyals per BOE, 0.36 SAR/kWh, 0.096 US$/kWh
- At 300 Saudi Riyals per BOE, 0.72 SAR/kWh, 0.192 US$/kWh
- At 375 Saudi Riyals per BOE, 0.90 SAR/kWh, 0.240 US$/kWh

The analysis in this report is based on the 36 Halala (9.6 U.S. cents) per kWh

Changes to the efficiency of air conditioner would have an immediate effect on the use of fuel. The effect of high temperature efficiency (as estimated by EER at T3) would also reduce capital costs, operations and maintenance, as well as transmission and distribution costs in the long term.

#### *3-4-4-7 Generation Cost to the Kingdom*

Generation costs in this study are taken from a 2008 Saudi Electric Company study (Alsherebi). The values used are:

- Capital Costs 5 Million SAR per MW (page 3)
- Manpower, Operations and Maintenance 0.2069 Million SAR per MWyear (Table 5 page 22)

Generating capacity was saved in this present study in increments of 500 MW.

### 3-4-5 Local Manufacturing Capabilities and Impact

The team visited air conditioner manufacturing facilities in Saudi Arabia to ascertain the local manufacturing capabilities. The team found the facilities capable of manufacturing tube and fin heat exchangers as well as metal components. The factories were capable of assembling, testing, and shipping the completed air conditioners. The heat exchanger manufacturing capabilities exhibited various levels of automation. There was no local capability to manufacture heat exchangers of other types, such as microchannel heat exchangers. Many components are imported, including compressors and motors.

The imported components, particularly compressors have long lead times and limited availability. This puts constraints on the speed at which improvements can be implemented.

### 3-4-6 KSAAC Development

#### *3-4-6-1 Baseline Unit Selection and Testing*

The four specified reference units were chosen in the work plan of the project and according to the decisions of the second meeting with officials and consultants of the Ministry of Water and Electricity and one of those decisions was the involvement of the four local manufacturers by selection one unit from the factory of each one of them, following the basic data of the reference units:

1. Window type conditioner of 18000 BTU with manufacturer claimed EER values of 7.87 under conditions of T1, 5.76 under conditions of T3 (represents the most used units in the EER value compatible with Saudi Standards selected from the products of National Air Conditioners Factory "ALISSA").
2. A window type conditioner of 18000 BTU with manufacturer claimed EER values of 8.00 under conditions of T1, 6.00 under conditions of T3 (represents a higher EER value compatible with Saudi Standards selected from the products of Saudi Air-conditioners Manufacturing Company / SAMCO).
3. Split unit conditioner of 24000 BTU with manufacturer claimed EER values of 8.00 under conditions of T1, 5.93 under conditions of T3 (represents the most used units in the EER value compatible with Saudi Standards selected from the products of Zamil Air Conditioners Factory).
4. Split unit conditioner of 24000 BTU with manufacturer claimed EER values of 8.75 under conditions of T1, 6.61 under conditions of T3 (represents a higher EER value compatible with Saudi Standards selected from the products of LG Factory Company Shaker Ltd).

As the purpose of reference units selection at external standard and high temperatures is to specify the real or actual efficiency of the reference units under similar operational conditions to the ordinary and peak operation, it was agreed to conduct the required tests of the reference units at the Lab of IKHTIYAR Company Limited in Dammam as it is the only accredited at the local and Gulf levels laboratory, and it has the potentials that allow the conduct of required tests and examinations to ensure the actual/real efficiency of those units.

The necessary arrangements were taken to conduct the tests according to the standard ISO 5151, the standard number SASO 2681/2007 in order to examine or test the units under external hard conditions, so as the tests / examinations included:

1. T1: Stable state performance (cooling capacity and energy efficiency ratio EER) under external temperature degree of 35C dry bulb/24C wet bulb, internal temperature of 27C db/19C wb (was conducted on all the four units.)
2. T1 internal conditions, T3 external conditions: Stable state performance (cooling capacity and energy efficiency ratio EER) under external temperature degree of 46C db/24Cwb, internal temperature of 27C db/19Cwb (was conducted on all the four units.)
3. T3: Stable state performance (cooling capacity and energy efficiency ratio EER) under external dry temperature degree of 46C db/24Cwb, internal temperature of 29C db/19Cwb (was conducted on the entire window type unit, and the split unit of the efficiency that is compatible with the Saudi Standard.)
4. Cycling T1 conditions: Periodic test 15 minutes operation (on) of the compressor and 15 minutes stop (off) (was conducted on the unit that is identical with the Saudi Standards.)

#### *3-4-6-2 Baseline Results*

These units are required to meet SASO Standard 2663 which includes the following criteria:

- Tested effective power input $\leq$1.10 x rated power.
- Tested cooling and heating capacity $\geq$0.95 x rated capacity.
- Tested EER $\geq$0.95 x rated EER.

The results are shown in Figure 12.

One of the units (E1) failed to perform within specifications with respect to:

- T1 and T3 EER
- T1 and T3 Capacity

A second unit (E2) was obtained from the manufacturer of the failing unit and tested at the same facility. The second unit produced 95.6% of its labeled capacity at T1. That unit failed to meet the standard since it produced only 90.62% of its rated capacity and efficiency at T3.

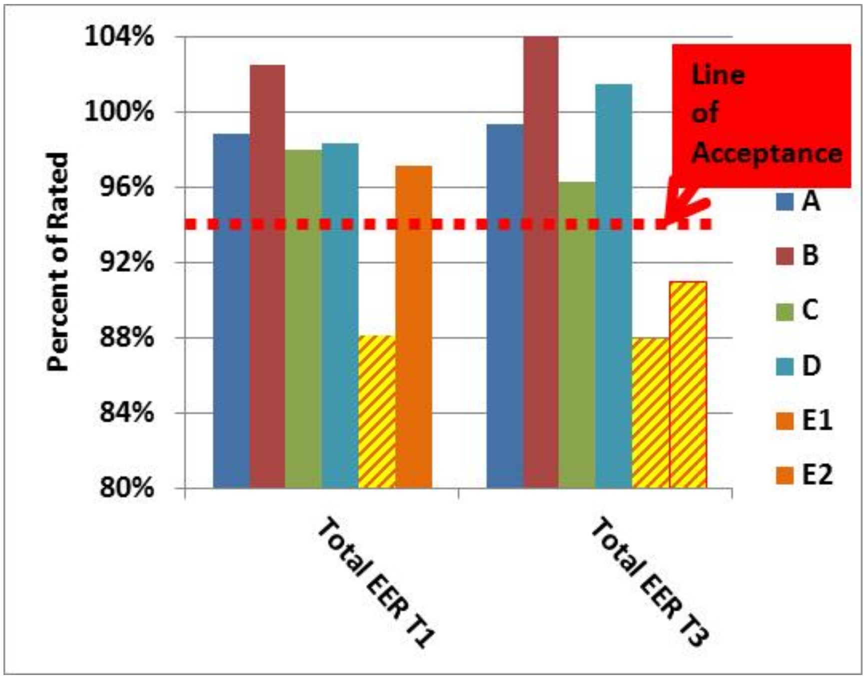


Figure 12 Laboratory Tests of Saudi Baseline Units

The data sheets for these tests are attached in Appendix B.

#### *3-4-6-3 Design Process*

This project used the process shown schematically in Figure 13.

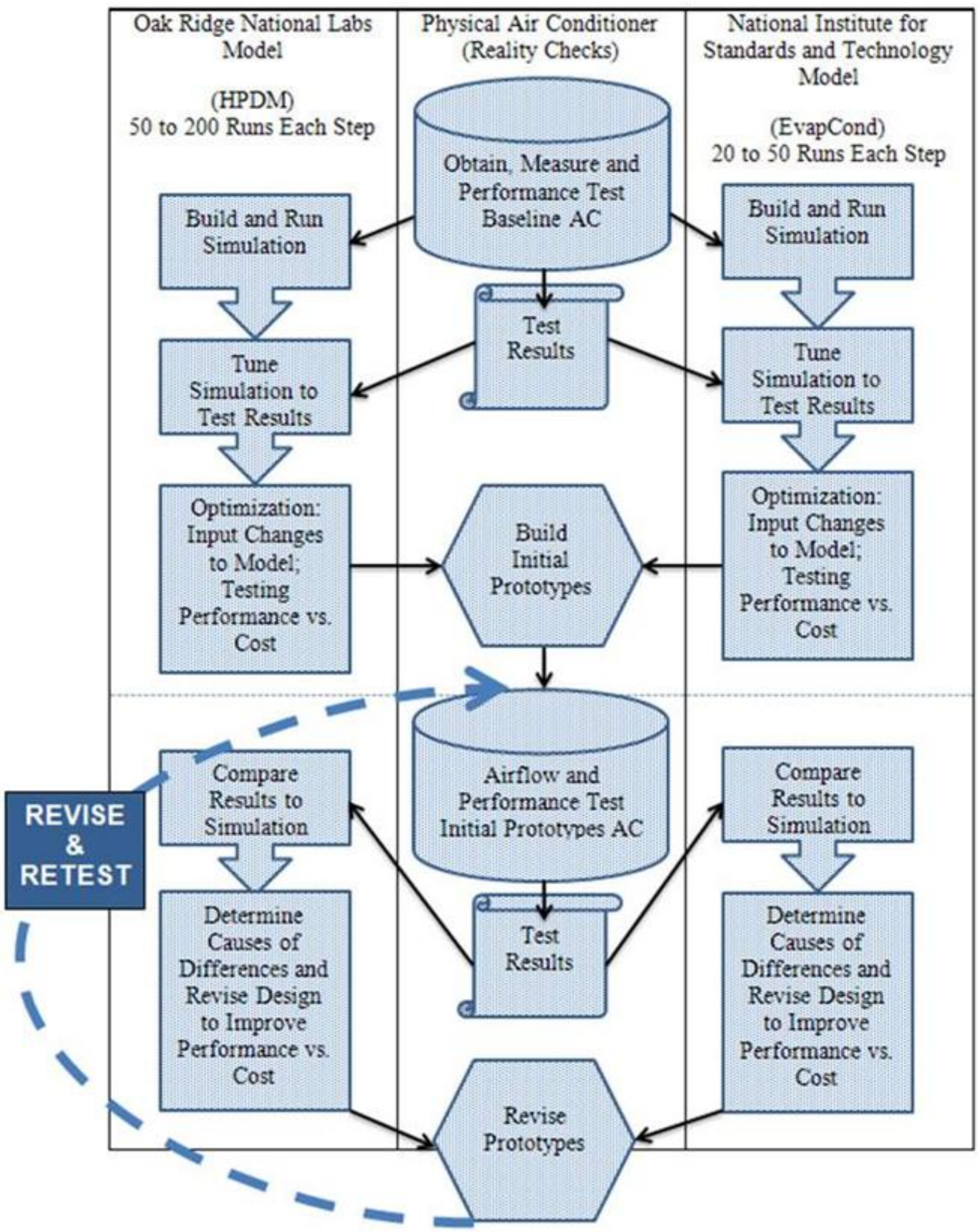


Figure 13 AC Design Process

The project design methodology was an iterative process of identifying potential improvements, testing the impact of improvements in simulation models and, when possible, in physical models in the laboratory, revising the design, and re-testing. During development of the final prototype, design modifications were vetted with a Saudi

Arabian air conditioner manufacturer to determine the practicality of implementation within the constraints of manufacturing capabilities, component availability, cost considerations, and the rigors of long-term operation in the Saudi Arabia climate. The overall methodology proceeded as follows:

1. Research to determine:
    a. Current technology
    b. New/emerging technologies
    c. General design improvement opportunities
    d. Component improvement opportunities
    e. Controls improvement opportunities
2. Simulation modeling to develop estimates of the impact of design changes
    a. ORNL heat pump model
    b. EvapCond heat exchanger model
3. Laboratory testing of design changes to US model window and mini split air conditioners in the Proctor Engineering Group laboratory
4. Work with Saudi Arabia air conditioner manufacturer to determine feasibility of implementing design changes
5. Laboratory testing of design changes to the project baseline window and mini split air conditioners at the Intertek Certified facility in Saudi Arabia
6. Work with Saudi Arabia air conditioner manufacturer to finalize prototype design
7. Test prototype window and mini split prototype air conditioners at the Intertek facility in Saudi Arabia
8. Revise prototype design as needed based on test results

#### 3-4-6-3-1 Research

A literature search was performed to determine to current status of window and mini split air conditioning technologies, new/emerging technologies that may improve energy performance, and regulatory and market trends that may influence the development and adoption of new technologies in the near future. Research was focused the U.S. market where comparatively stringent energy performance standards may drive technology advancements ahead of the global market. Technology trends in Europe and Asia were also researched. .

The literature search identified four key categories of opportunity, with similar findings and recommendations worldwide.

1. Heat exchangers
    a. Increased face area – Heat exchangers with larger face area are more efficient and provide greater capacity than smaller heat exchangers. This is widely known throughout the HVAC industry but the indoor coil of mini split air conditioners and both coils of window air conditioners are space

constrained, limiting the opportunity to improve efficiency through larger heat exchange coils.

b. Increased number of tube rows – For space constrained coils where increasing the face area is not possible, increasing the number of tube rows can increase the effective size of the heat exchanger resulting in greater capacity and efficiency. Each additional tube row sees a smaller temperature differential to the air stream due to heat transfer from the tube rows upstream. Additional tube rows also increase the coil resistance to refrigerant flow and to airflow through the coil. For these reasons, there is little efficiency benefit to greater than three tube rows.
c. Improved fin design – Louvered, slit, and other fin designs exist which can improve coil heat transfer. Likewise, an increased number of fins can also improve heat transfer. Challenges associated with modifying the fin design include increased resistance to airflow and an increased propensity to trap dust that may negatively impact long term performance, particularly in unusually dusty climates such as Saudi Arabia.
d. Smaller diameter copper tube – Copper tube heat exchangers with tube diameters smaller than 7mm are being heavily promoted by the copper industry in response to competition from aluminum heat exchanger manufacturers. Anecdotal efficiency benefits are sometimes mentioned, but the primary purpose is as a cost saving measure due the reduction in copper material required to manufacture.
e. Microchannel – Flat tube microchannel heat exchangers are available in both copper and aluminum construction but aluminum is more common. These heat exchangers are widely used in automotive applications and have emerged in the residential and commercial central air conditioning markets over the past five years. Benefits include a higher ratio of surface area to heat exchanger volume and lower resistance to airflow across the coil. Their primary use in residential and commercial HVAC is as the condenser coil for air conditioning applications. The flat tube design presents challenges to moisture drainage which limits the current application as evaporator coils or in heat pump applications.
f. De-superheater – De-superheaters are small heat exchangers used to reduce the temperature above the saturation point of refrigerant vapor exiting the compressor. This may be accomplished through heat exchange with air, colder refrigerant entering the compressor, or water. By bringing the superheated refrigerant closer to the condensing temperature, de-superheaters enable more of the condenser coil volume to be used for phase change.

2. Compressor – Compressors represent the greatest opportunity for efficiency improvement in window and mini split air conditioners. The compressor is the most costly component of these systems and higher efficiency can dramatically increase cost to the consumer. Other considerations in compressor selection include refrigerant type, physical size of the compressor shell, and suitability for use in high ambient applications.
    a. Refrigerant R-22 compressors are commonly available. With the approaching phase-out of R-22, R-410A models have become increasingly available while R-407C model availability remains extremely limited to non-existent in the efficiency levels required for this project.
    b. Physical size is critical for space constrained applications such as window air conditioners.
    c. "Tropical" compressor models are commonly used by air conditioner manufacturers in very hot regions such as Saudi Arabia. These models are designed for increased durability under very hot ambient conditions. Given the lesser demand for these, the compressor manufacturers are slow to put resources into developing new compressor designs for this market.
3. Fans and Motors
    a. Indoor fans – The indoor fans of window air conditioners are centrifugal type blowers with a molded Styrofoam housing. The indoor fan of mini split air conditioners are cross flow fans. The outdoor fans of both window and mini split systems are propeller type fans. Higher airflow across heat exchange coils improves heat transfer and increases capacity and efficiency. Improvement opportunities may include fan blade and housing optimization, enlarged diameter blower wheels, enlarged depth blower wheels, higher RPM motors, and airflow path optimizations.
    b. Brushless Permanent Magnet (BPM) motors – Variable speed BPM motors operate at efficiencies as high as 90% compared to 60% to 70% for the standard permanent split capacitor (PSC) motors. BPM motors retain their efficiency at reduced speeds while PSC motors become less efficient as their speed is reduced.
4. Controls
    a. Thermostatic controls – Thermostatic controls allow the air conditioner to cycle on and off as needed to achieve a temperature setpoint. These controls can reduce energy use by allowing the air conditioner compressor to turn off when the space has been cooled sufficiently.
    b. Fan cycling – Fan cycling controls allow the fan to cycle on and off periodically when the compressor is not on. This enables the occupant to circulate air around the room without incurring the energy penalty of running the fan 100% of the time.

c. Variable speed controls – Inverter driven variable speed controls are primarily used in mini split applications. By running at reduced speed during times of reduced demand the system essentially operates as if it were a very small compressor paired with very large heat exchangers, which can significantly improve efficiency. The benefit is reduced or eliminated during times of high demand. Since the efficiency increase at reduced load is not captured by the current steady state standard, there is little impetus to use this technology.
d. Occupancy sensors – Both mini splits and window units continue to run whether there is an occupant in the room or not. This can lead to unnecessary electrical use.

#### 3-4-6-3-2 Simulations

Two simulation modeling programs were used to develop and estimate the performance impact of air conditioner design modifications:

The Mark VII heat pump model developed by Oak Ridge National Laboratory considers the entire air conditioning or heat pump system, with general inputs for component performance and heat exchanger geometry.

The EvapCond heat exchanger modeling software, developed by the National Institute of Standards and Technology, considers only the heat exchanger and enables detailed modeling and optimization of heat exchanger designs.

#### *ORNL Mark VII*

Baseline simulation models were developed in the ORNL Mark VII software following laboratory testing of the baseline air conditioners. The initial models were developed using physical specifications and component performance characteristics provided by the equipment manufacturers. The models were then tuned to match the baseline laboratory measurements as closely as possible.

To analyze the performance impacts of various design modifications, the desired modifications were input into the models and the outputs were compared to the baseline data. Hundreds of model runs were performed to analyze potential design modifications individually and in combinations. Modifications tested in the ORNL simulation include:

- Increased indoor and outdoor airflow
- Increased indoor and outdoor heat exchanger fin density
- Increased indoor and outdoor coil face area
- Interactions between indoor and outdoor heat exchange improvements
- Smaller tube heat exchangers
- Increased number of heat exchanger tube rows

- Increased number of heat exchanger circuits
- Capillary tube length
- Higher efficiency compressors
- Compressor sizing
- Refrigerant R407C compressors
- Compressor discharge line de-superheater using condensate for the window AC

Key findings of the ORNL simulations are as follows:

### *Compressor*

Various compressor models were tested in the simulation. This required obtaining detailed compressor performance specifications from the manufacturer. Compressor map coefficients for refrigerant mass flow rate and power per ARI 540-99 are required. This information is readily available from U.S. manufacturers for U.S. models, but was very difficult to obtain from manufacturers in Asia for the compressor models being considered for use in this project. In most cases it was necessary to manually read a large number of data points from performance charts provided by the manufacturers and derive the necessary coefficients through regression analysis.

The ARI 540-99 representation is of the form:

$$F(TS,TD) = C1 + C2TS + C3TD + C4TS^2 + C5TDTS + C6TD^2 + C7TS^3 + C8TDTS^2 + C9TSTD^2 + C10TD^3$$

Where:

TS is the refrigerant saturation temperature at compressor suction

TD is the refrigerant saturation temperature at compressor discharge

In most cases for the compressor models from India and Asia it was necessary to derive the coefficients C1 – C10 from charts such as Figure 14. In the U.S. these coefficients are readily available from the compressor manufacturers.

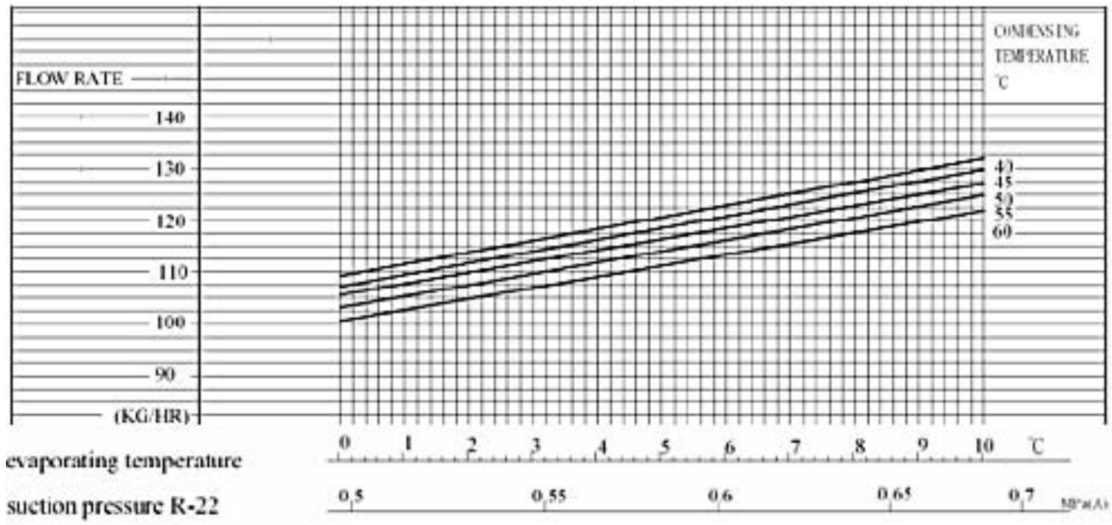


Figure 14 Compressor Performance Chart

Various compressor sizes were also considered. The baseline units contained compressors with higher rated capacity than the rated capacity of the air conditioner. One compressor manufacturer stated that 10% oversizing is standard practice to overcome heat exchanger sizing limitations and high ambient temperatures. Compressor oversizing does increase air conditioner capacity somewhat, but does so at the expense of efficiency. The simulations results indicated that smaller capacity compressors could deliver the necessary capacity at higher efficiency if heat exchanger effectiveness can be improved.

Compressors using R-22 and R-407C were considered. The simulations predicted poorer performance with R-407C compared to R-22 for both capacity and efficiency.

Results for select compressors tested in the simulations are shown below.

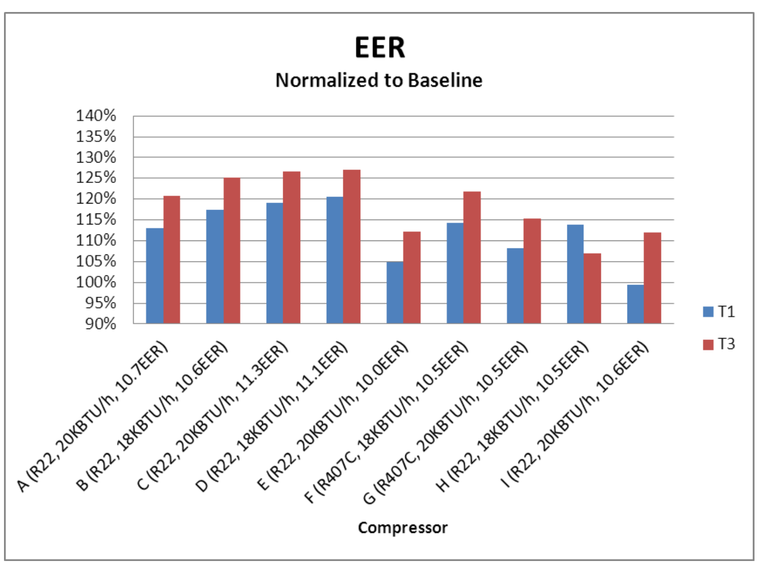


Figure 15 Simulation Results – EERs for Various Compressors on Window Unit

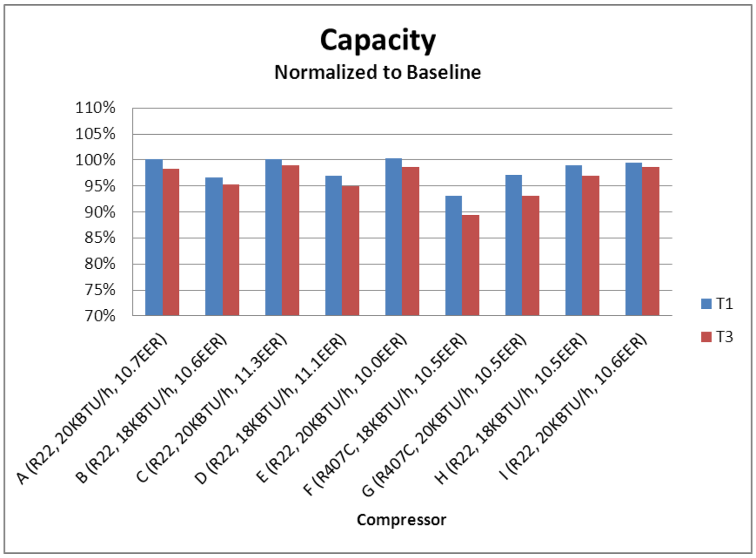


Figure 16 Simulation Results – Capacities for Various Compressors on Window Unit

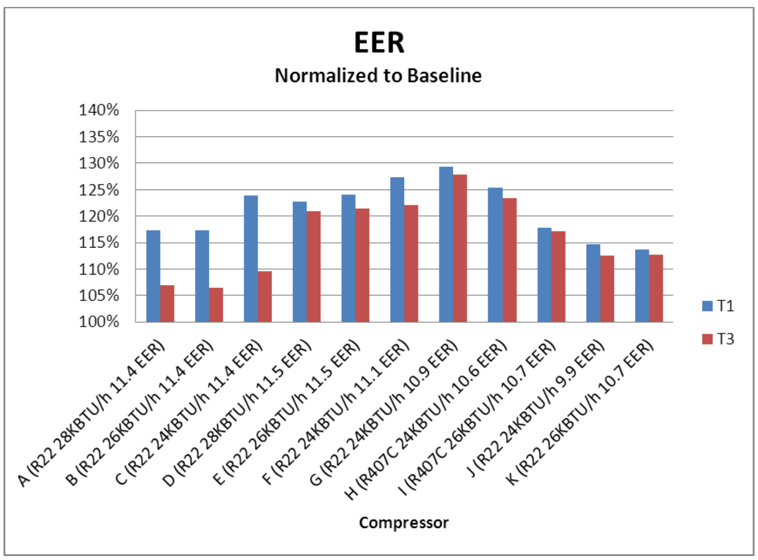


Figure 17 Simulation Results – EERs for Various Compressors on Mini Split Unit

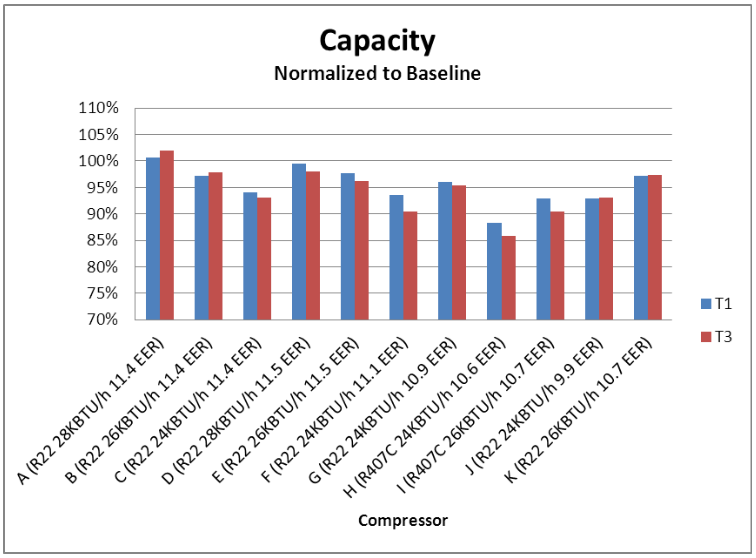


**Figure 18 Simulation Results – Capacities for Various Compressors on Mini Split Unit**

### *Airflow*

Airflow volume and uniformity of the distribution of airflow and air velocity across the heat exchange coils play a major role in capacity and efficiency. Modeling was performed to evaluate the potential improvement resulting from improvements to the indoor and outdoor airflow. Improvements were evaluated in increments of 10% of baseline airflow. Energy consumption of the fan motor was excluded from this analysis because while in general higher airflow can be expected to increase fan power, some improvements such as reducing air recirculation through the fan or improving the distribution of airflow may not.

The airflow modeling results are presented as surface charts in order to show the relative importance of indoor vs. outdoor airflow improvements, as well as interactions between improvements to airflow across the two heat exchangers.

Total EER for the window unit is more dependent upon outdoor coil airflow, while sensible EER and total and sensible capacity depend more heavily upon airflow through the indoor coil.

Total EER for the mini split unit shows lower overall improvement potential with increased airflow compared to the window AC and the improvement potential is more evenly balanced between the indoor and outdoor coil. Sensible EER and total and sensible capacity for the mini split are heavily dependent up on airflow through the indoor coil.

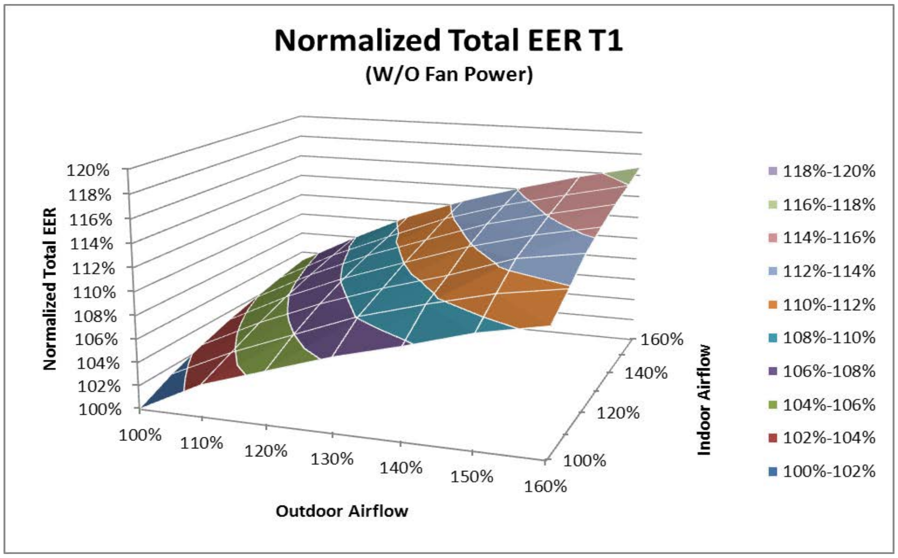


**Figure 19 Simulation Results -- EER vs. Airflow Window Unit (T1)**

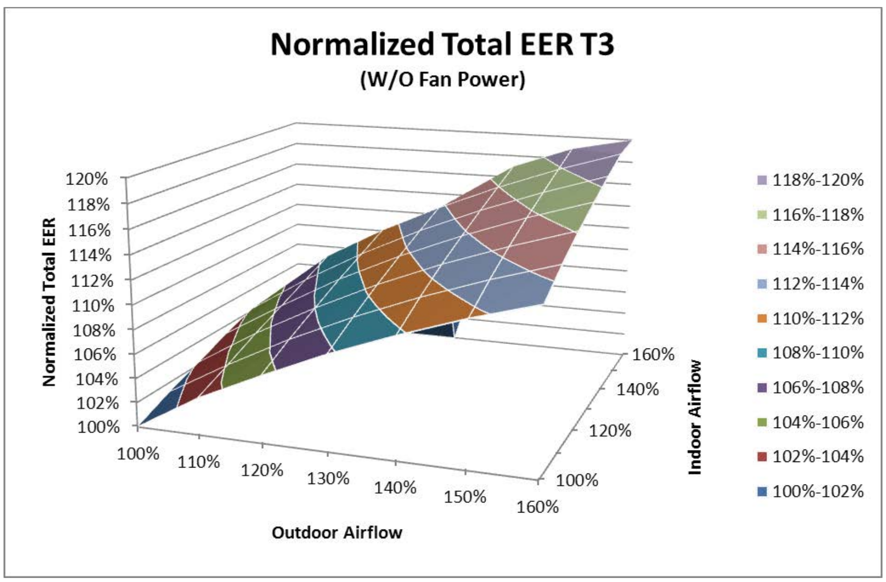


**Figure 20 Simulation Results -- EER vs. Airflow Window Unit (T3)**

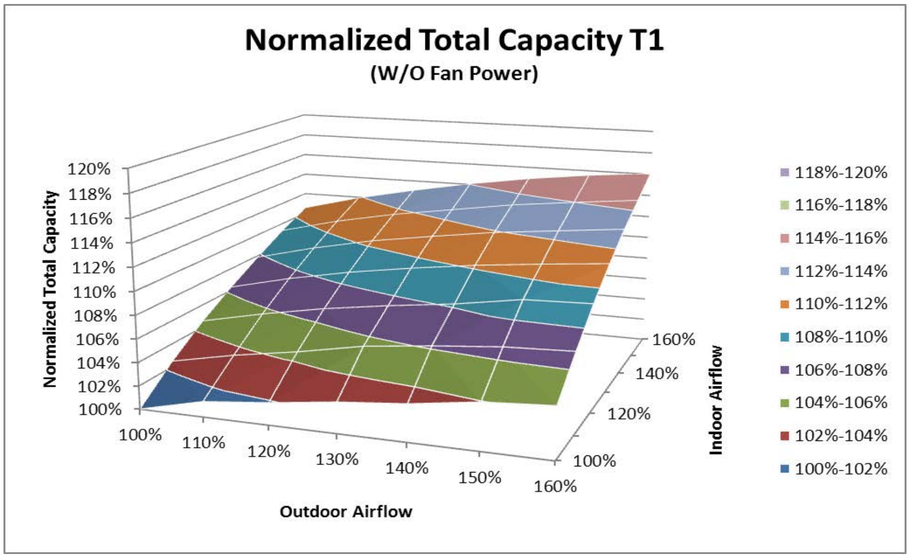


Figure 21 Simulation Results -- Capacity vs. Airflow Window Unit (T1)

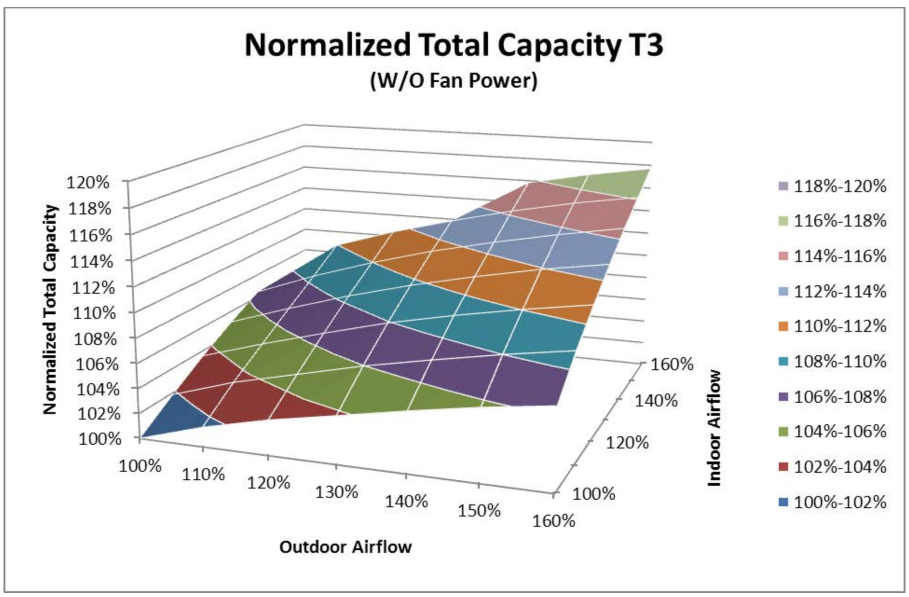


Figure 22 Simulation Results -- Capacity vs. Airflow Window Unit (T3)

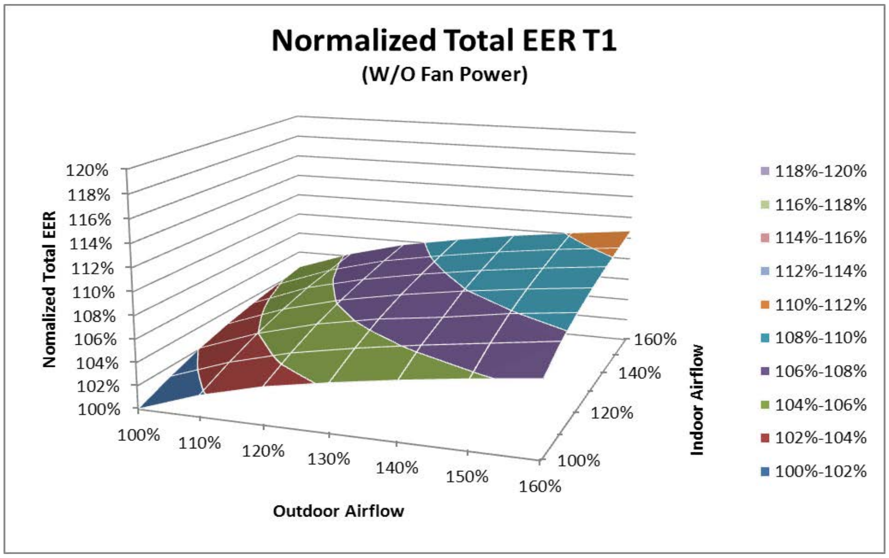


Figure 23 Simulation Results -- EER vs. Airflow Mini-Split (T1)

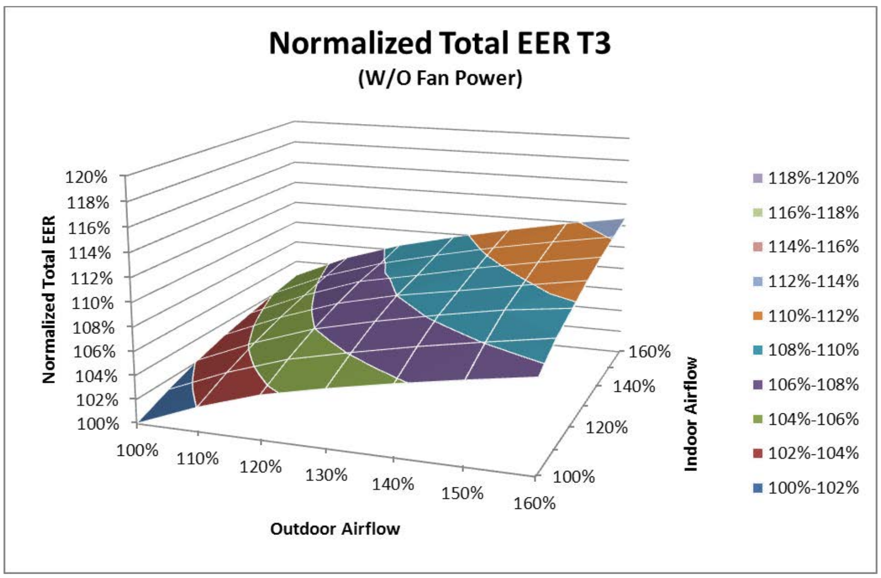


Figure 24 Simulation Results -- EER vs. Airflow Mini-Split (T3)

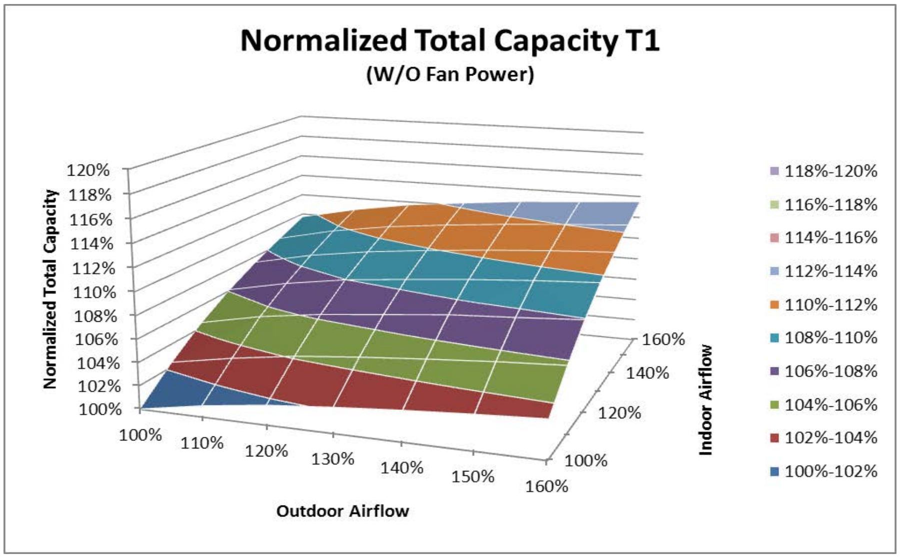


Figure 25 Simulation Results – Total Capacity vs. Airflow Mini-Split (T1)

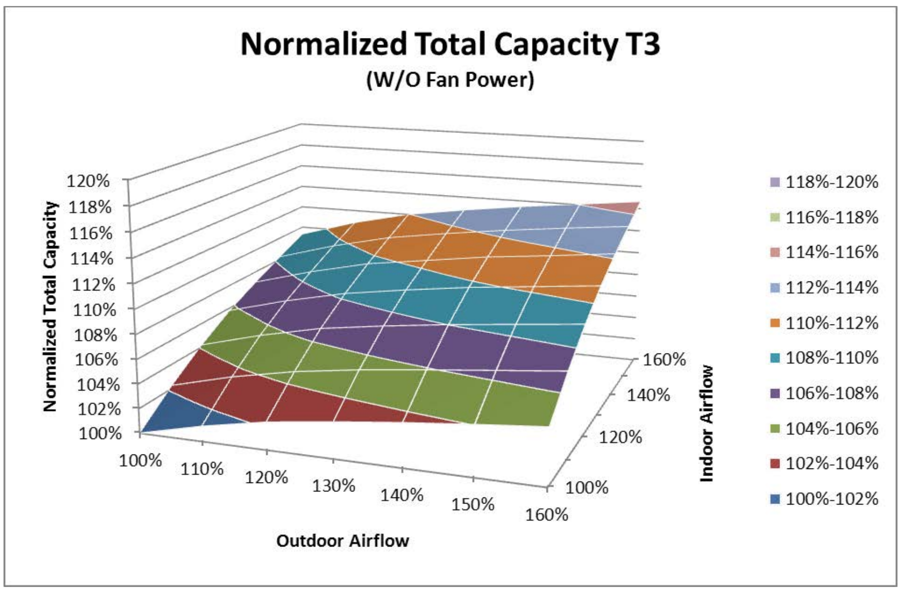


Figure 26 Simulation Results – Total Capacity vs. Airflow Mini-Split (T3)

### *Heat Exchanger Fin Spacing*

Modeling was performed to evaluate the potential improvement resulting from increasing the fin density on the indoor and outdoor heat exchanger coils. Improvements were evaluated in increments of 2 fins per inch. Energy consumption of the fan motor was excluded from this analysis.

The fin density modeling results are presented as surface charts in order to show the relative importance of indoor vs. outdoor fin spacing, as well as interactions between improvements to the two heat exchangers.

Of the two units, the window AC shows greater modeled improvement potential from increasing the fin density on the heat exchange coils. Efficiency gains are more dependent upon increasing the fins density of the outdoor coil, while capacity gains depend on both coils.

The ability to increase the fin density of the outdoor coil may be limited due to concerns about the coil becoming clogged with dust. However, the indoor coil is protected by a filter and the modeling results indicate that tighter fin spacing on the indoor coil can increase the air conditioner capacity which may enable downsizing the compressor to more closely match the air conditioner design capacity.

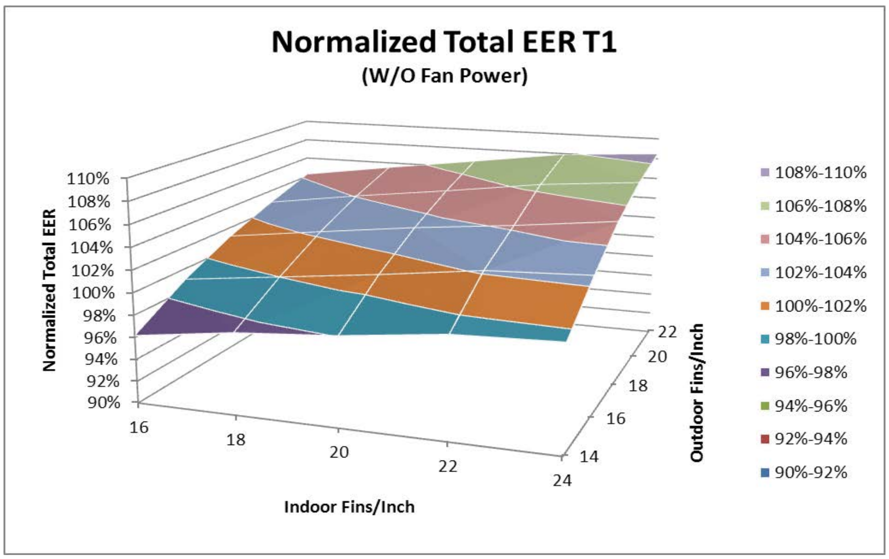


Figure 27 Simulation Results -- EER vs. Fin Density Window Unit (T1)

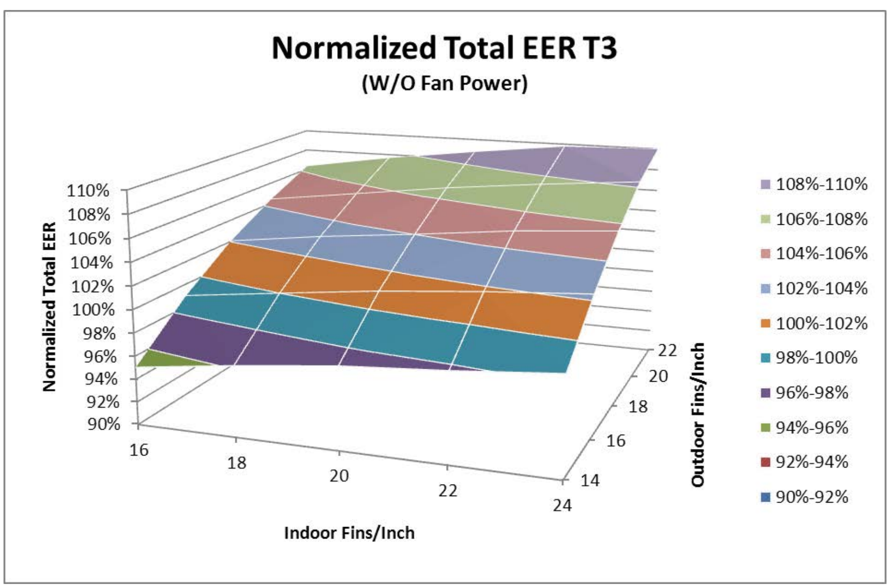


Figure 28 Simulation Results -- EER vs. Fin Density Window Unit (T3)

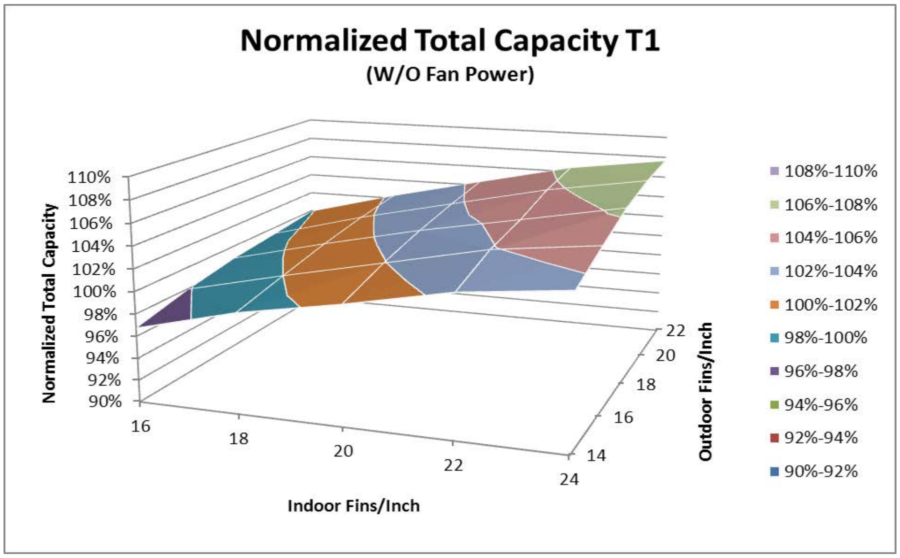


Figure 29 Simulation Results – Total Capacity vs. Fin Density Window Unit (T1)

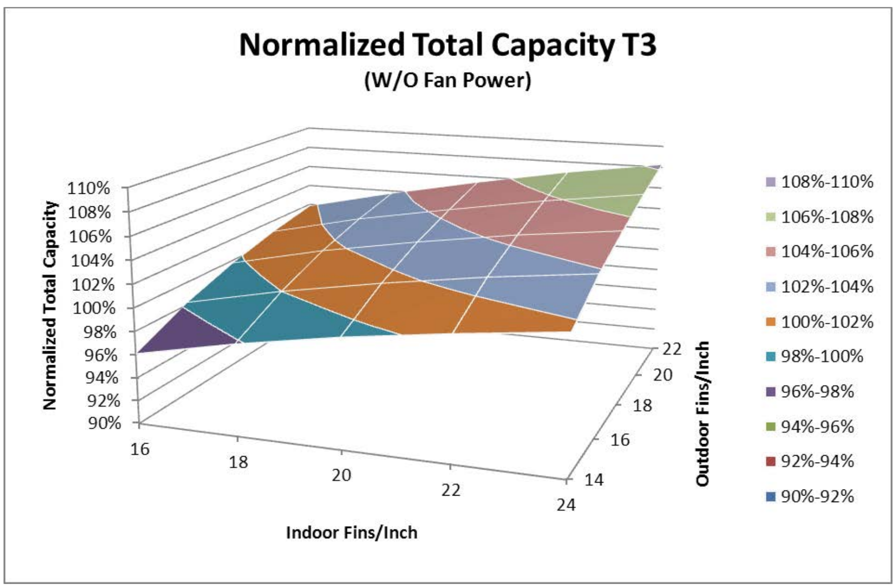


Figure 30 Simulation Results – Total Capacity vs. Fin Density Window Unit (T3)

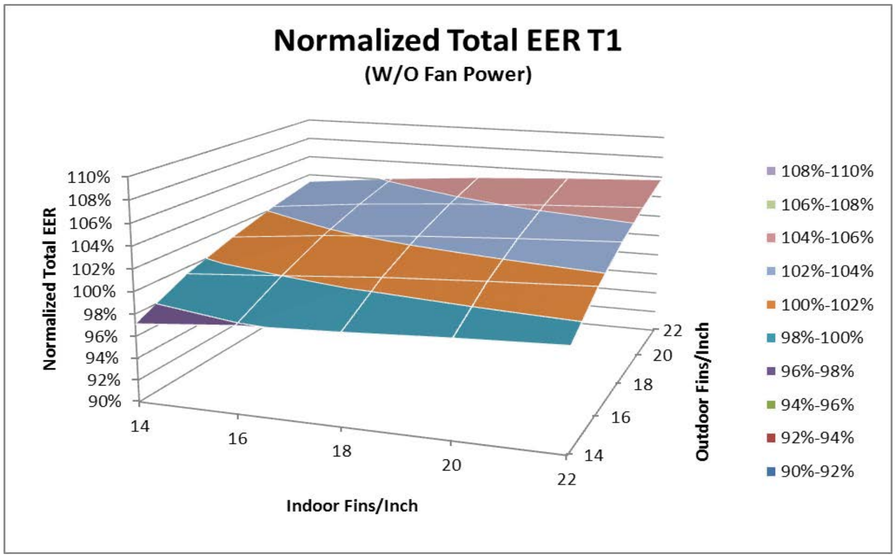


Figure 31 Simulation Results -- EER vs. Fin Density Mini-Split (T1)

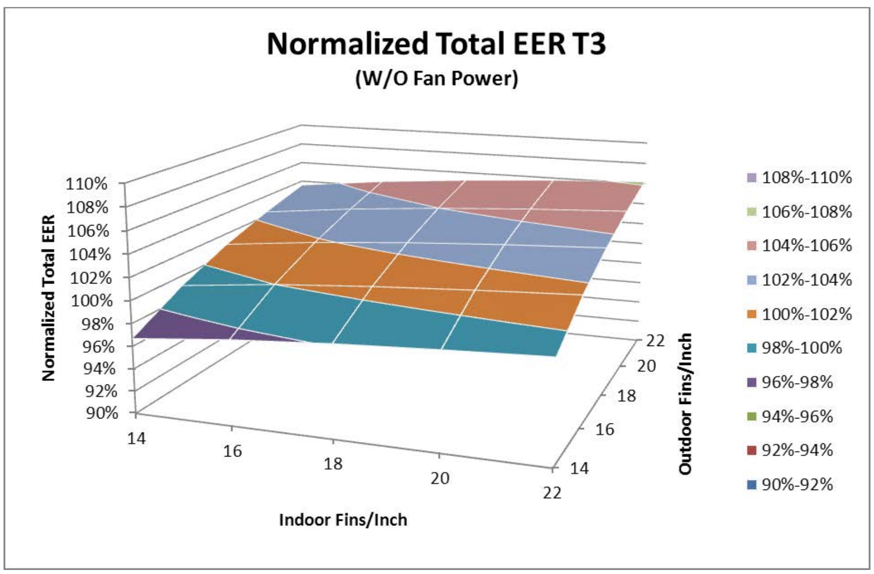


Figure 32 Simulation Results -- EER vs. Fin Density Mini-Split (T3)

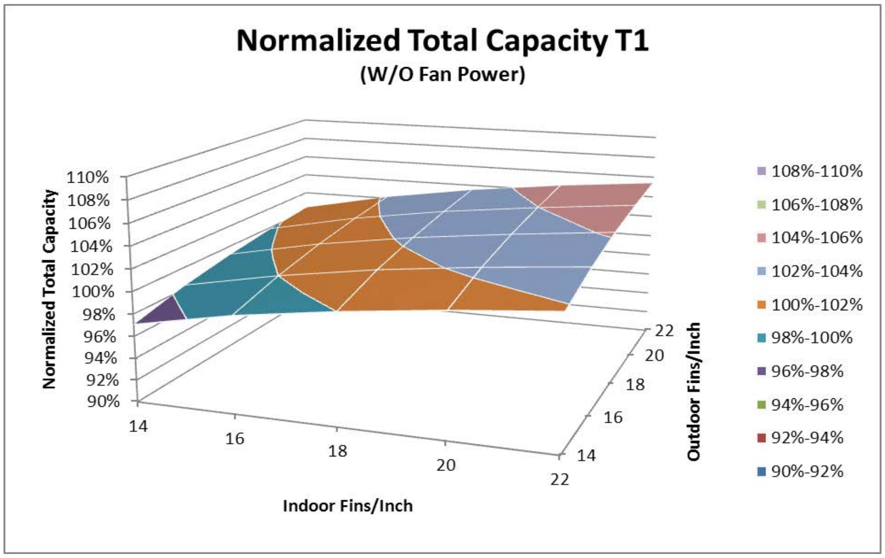


Figure 33 Simulation Results – Total Capacity vs. Fin Density Mini-Split (T1)

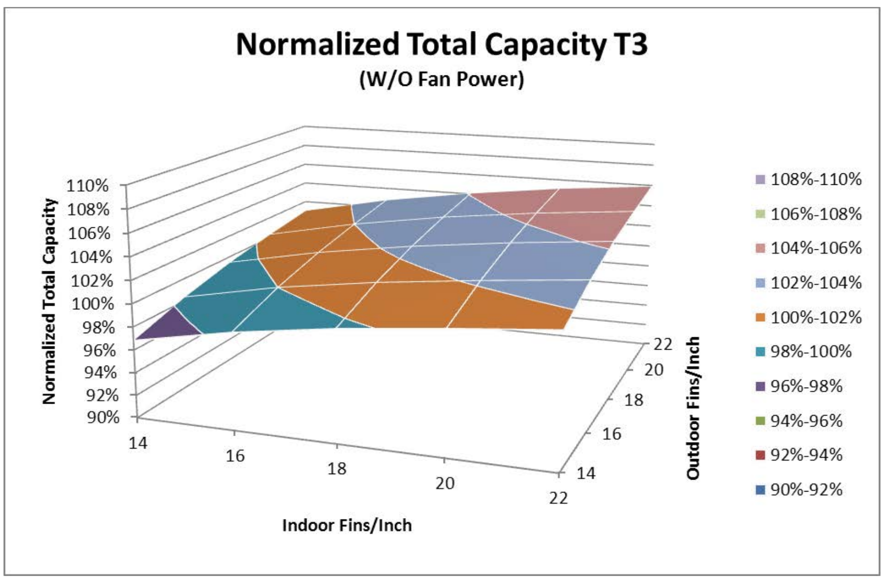


Figure 34 Simulation Results – Total Capacity vs. Fin Density Mini-Split (T3)

### *NIST EvapCond*

EvapCond is a heat exchanger modeling software that considers refrigerant circuiting within the coil as well as airflow profile across the coil. Hundreds of coil configurations were modeled for both evaporator and condenser coils for the window and mini split air conditioners. The coil designs that provided the maximum capacity and uniform refrigerant flow characteristics when interacted with the known air velocity profile were selected.

The configuration of the circuits and velocity profile are entered graphically as shown in the figure below.

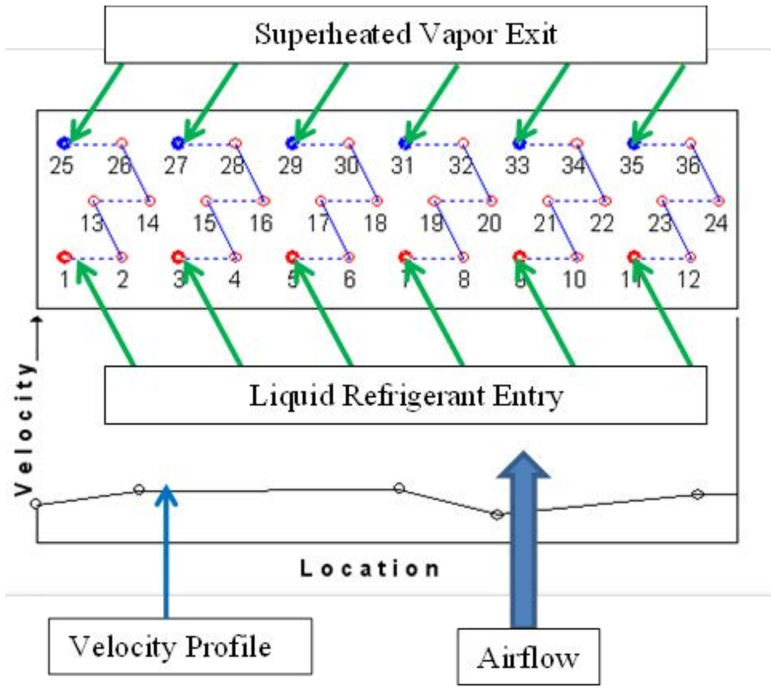


**Figure 35 EvapCond Simulation – Evaporator Coil Refrigerant Circuit and Velocity Graphic Input**

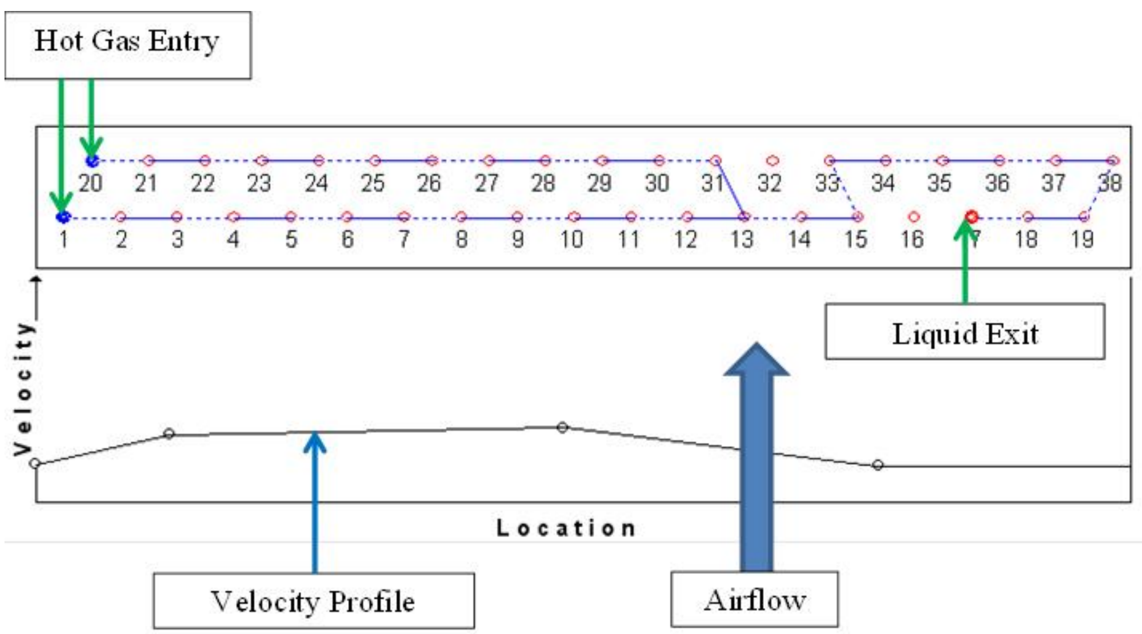


**Figure 36 EvapCond Simulation – Condenser Coil Refrigerant Circuit and Velocity Graphic Input**

*Airflow*

The airflow through a coil and its velocity distribution affect the available capacity of a heat exchanger. Increased airflow provides two advantages. First it increases the total capacity and gross EER of the unit. Second it increases the sensible heat ratio, which is very important for dry climates. The results of modeled increases in airflow from EvapCond illustrate only the increase in EER since the evaporator saturation temperature is assumed constant. On the negative side, increased airflow sometimes requires increased fan watt draw, higher velocities can produce a condensate water spray, and higher velocities can increase noise. These negative effects can be counter acted to some degree with improvements in the airflow pathways, fan design, and fan motor efficiency.

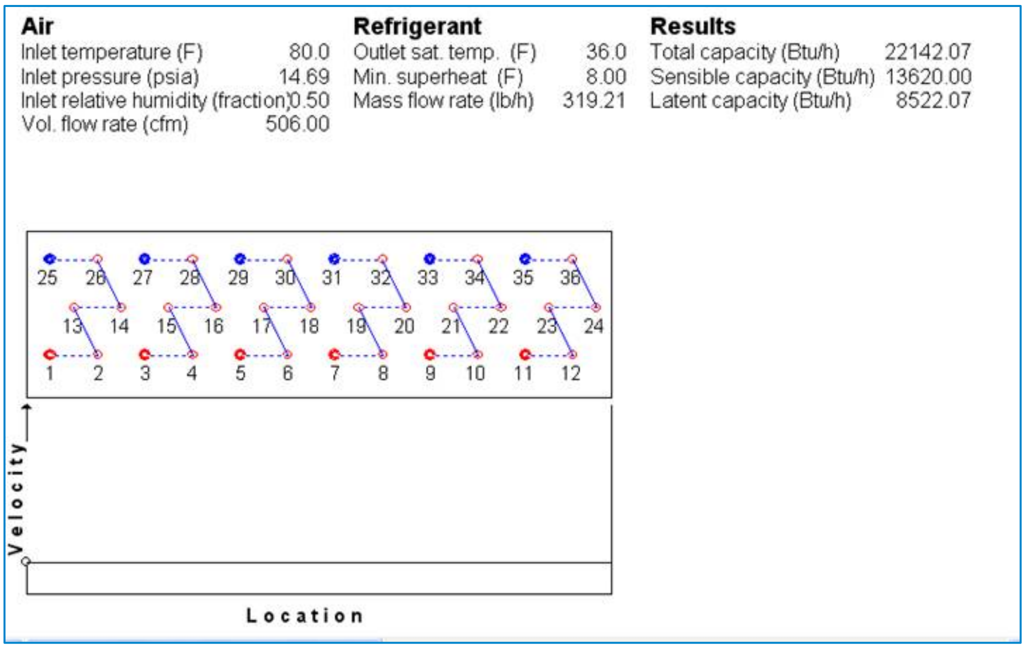


Figure 37 Mini-Split AC EvapCond Simulation – Baseline Evaporator Airflow

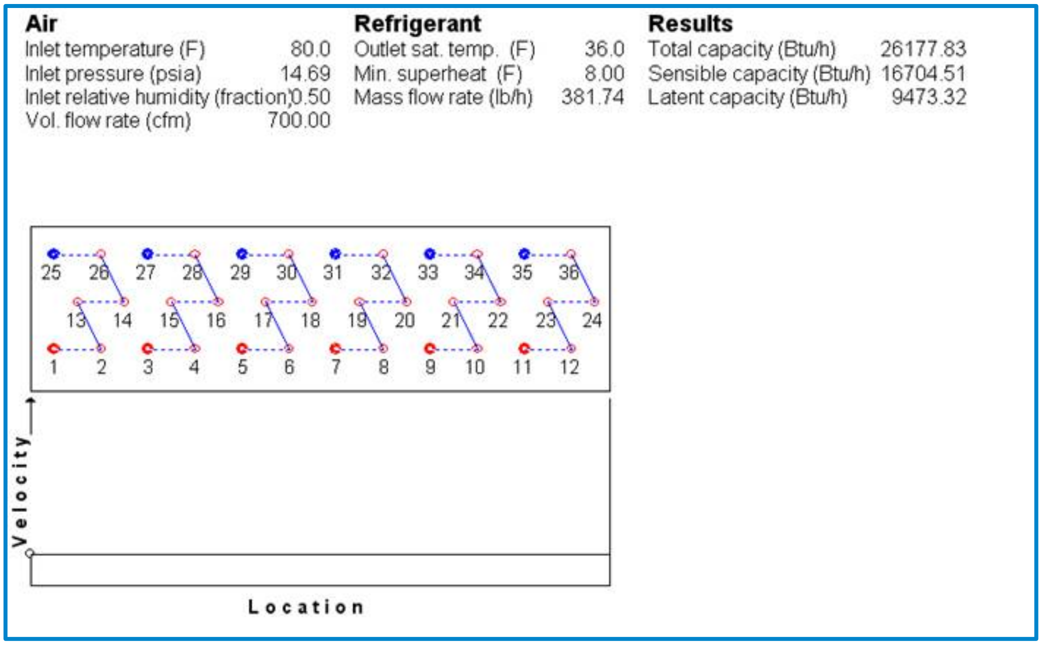


Figure 38 Mini-Split AC EvapCond Simulation – Increased Evaporator Airflow

### *Refrigerant Circuits*

EvapCond produces estimates of capacities as the refrigerant circuitry is changed. The figures below show the baseline circuitry and the proposed circuitry for the evaporators and condensers of both the window and mini-split units.

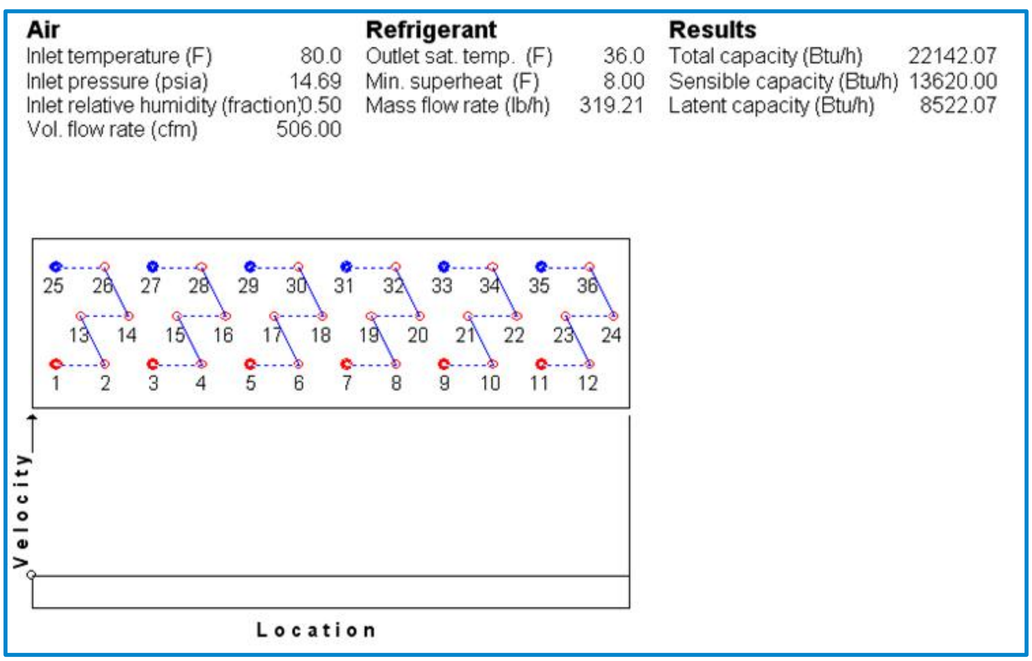


Figure 39 Mini-Split AC EvapCond Simulation – Baseline Evaporator

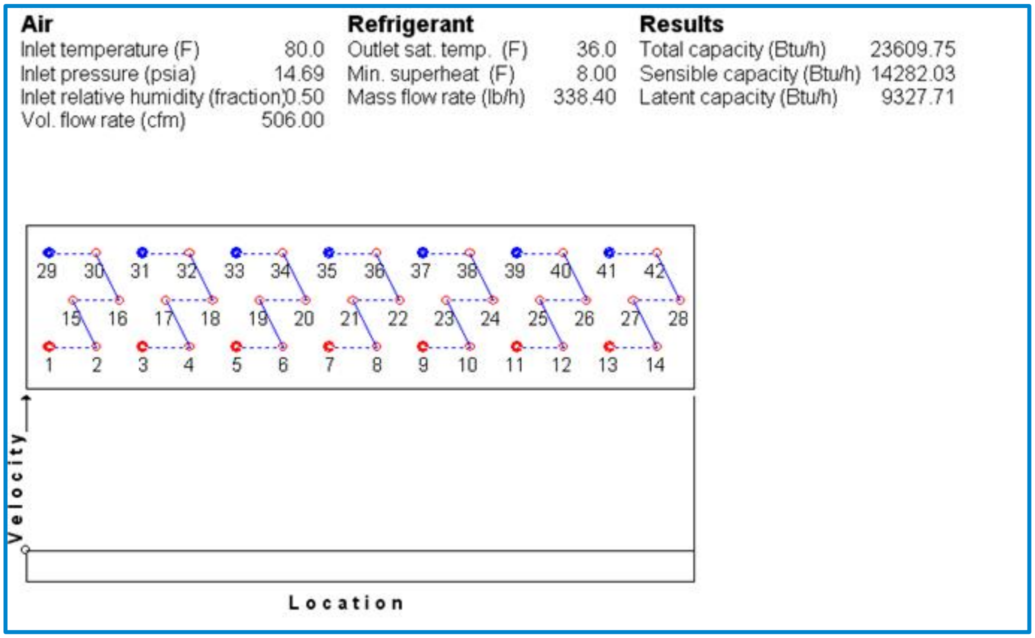


Figure 40 Mini-Split AC EvapCond Simulation – Proposed Evaporator

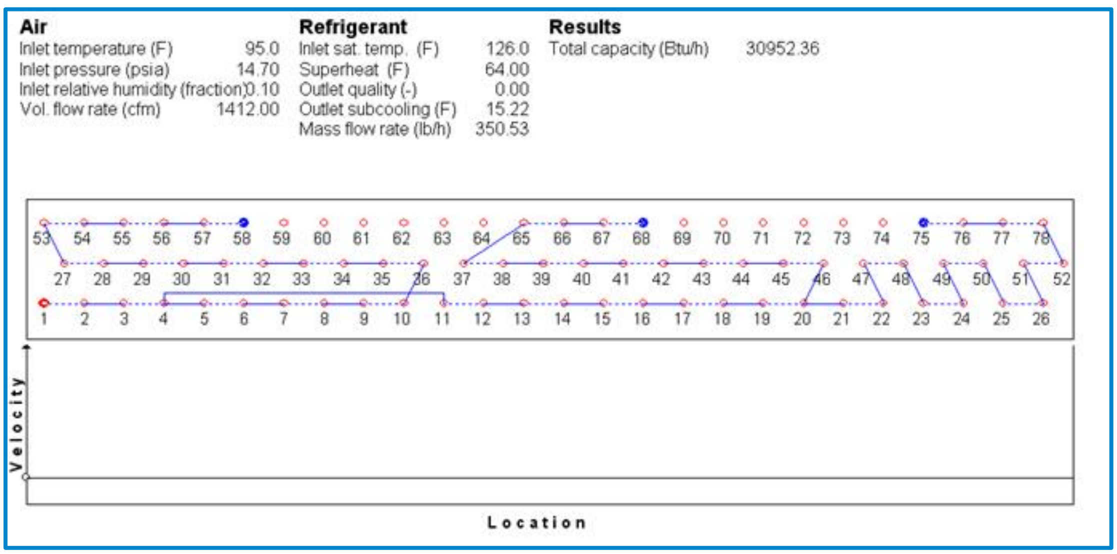


Figure 41 Mini-Split AC EvapCond Simulation – Baseline Condenser (actual liquid header could not be modeled in EvapCond)

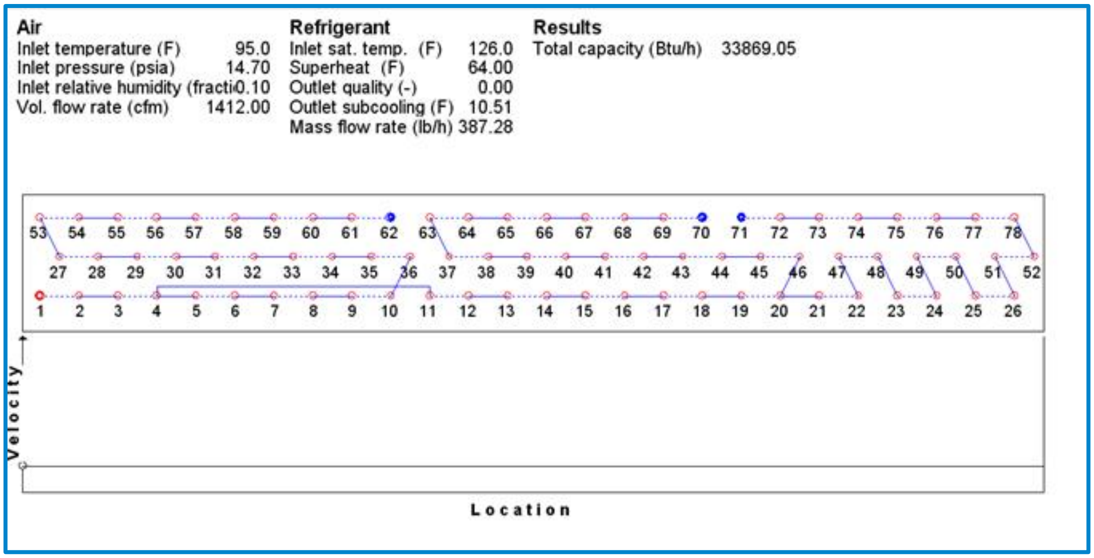


Figure 42 Mini-Split AC EvapCond Simulation –Condenser with Infilled Rows

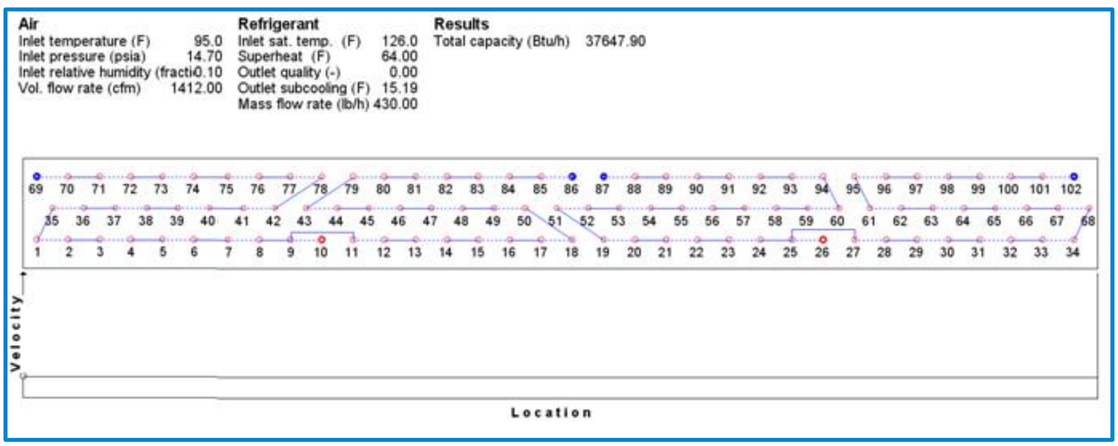


Figure 43 Mini-Split AC EvapCond Simulations – Proposed Tall Condenser

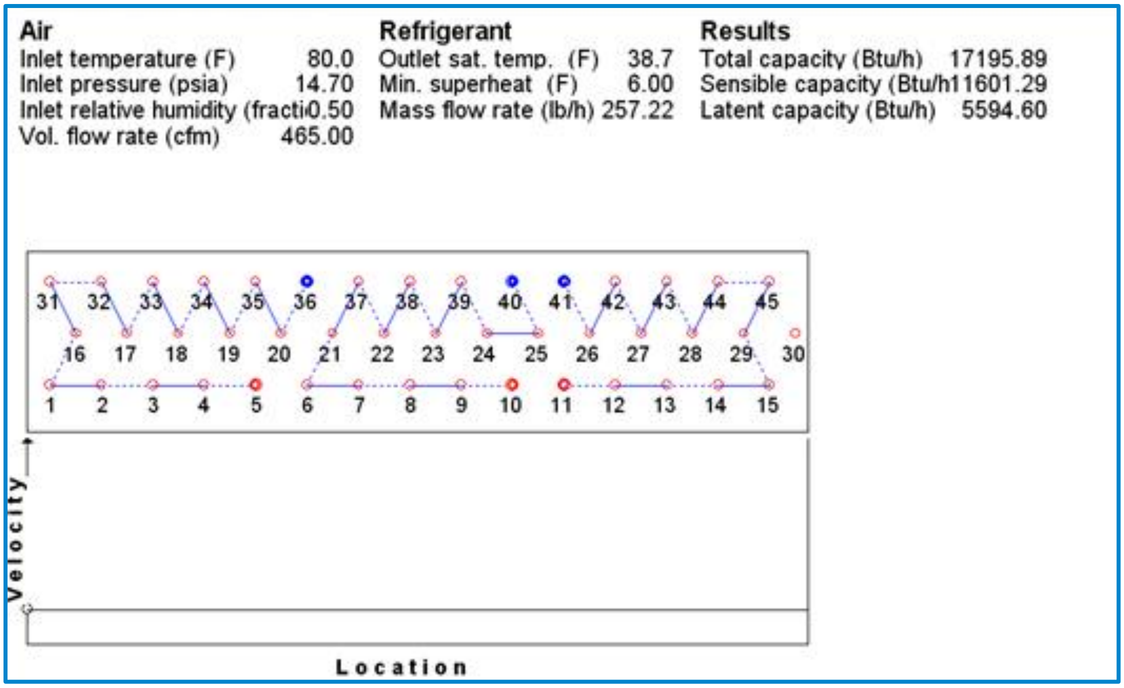


Figure 44 Window AC EvapCond Simulation – Baseline Evaporator

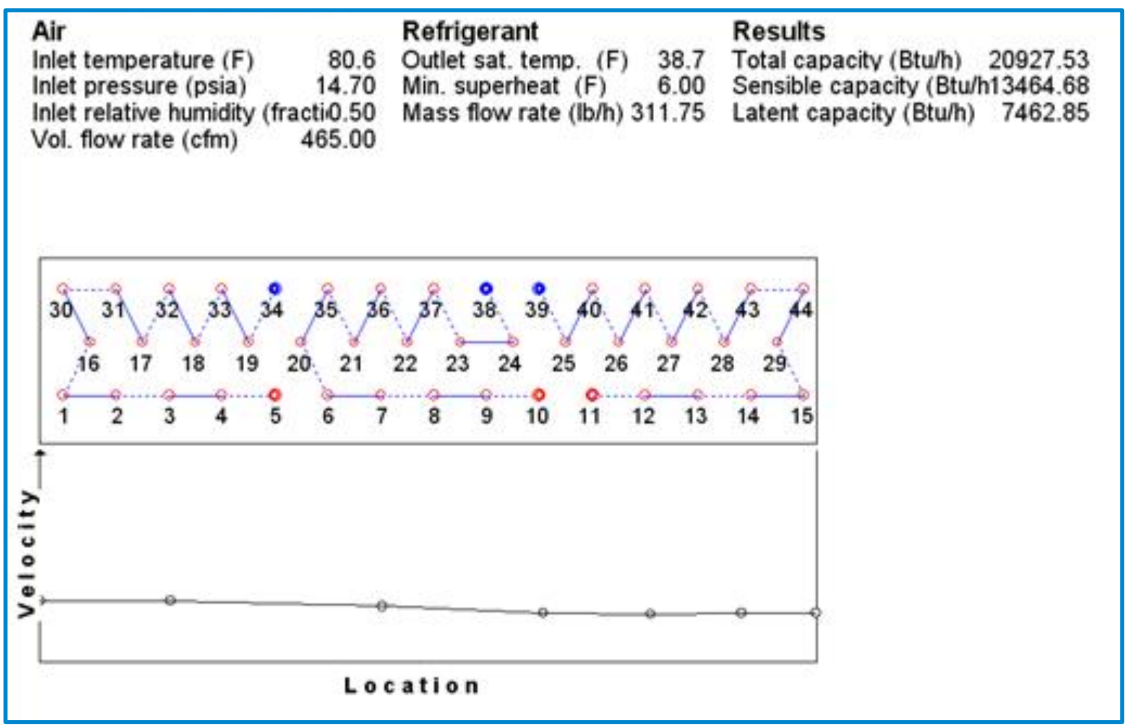


Figure 45 Window AC EvapCond Simulation – Proposed Evaporator Based on Velocity Profile

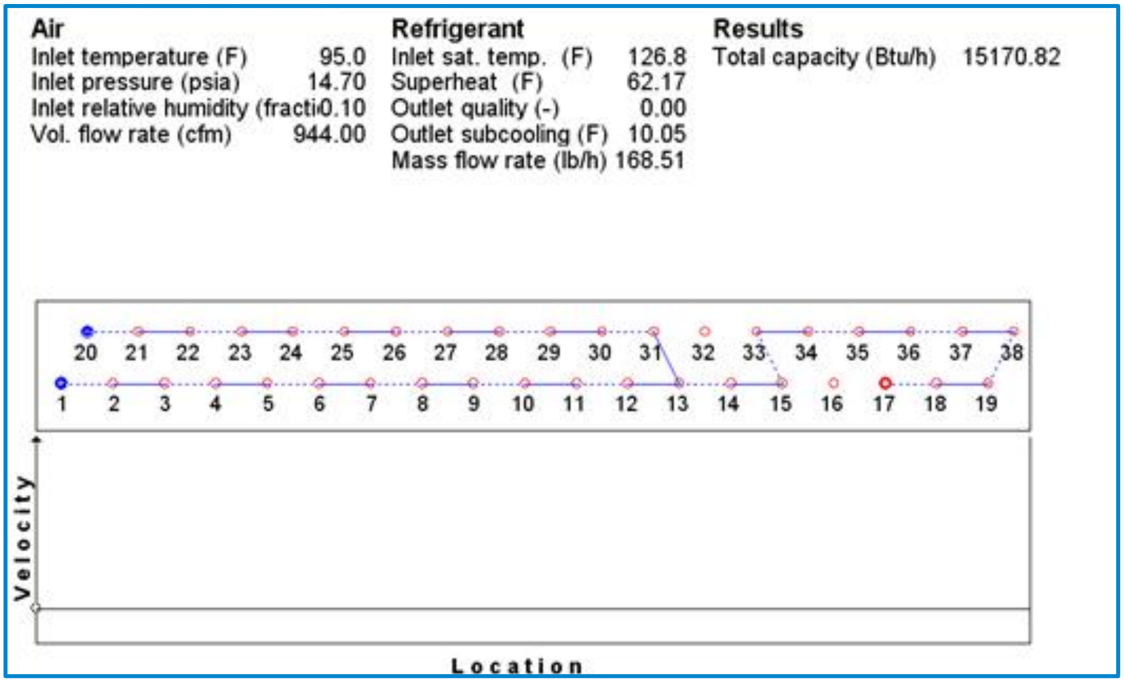


Figure 46 Window AC EvapCond Simulation – Baseline Condenser

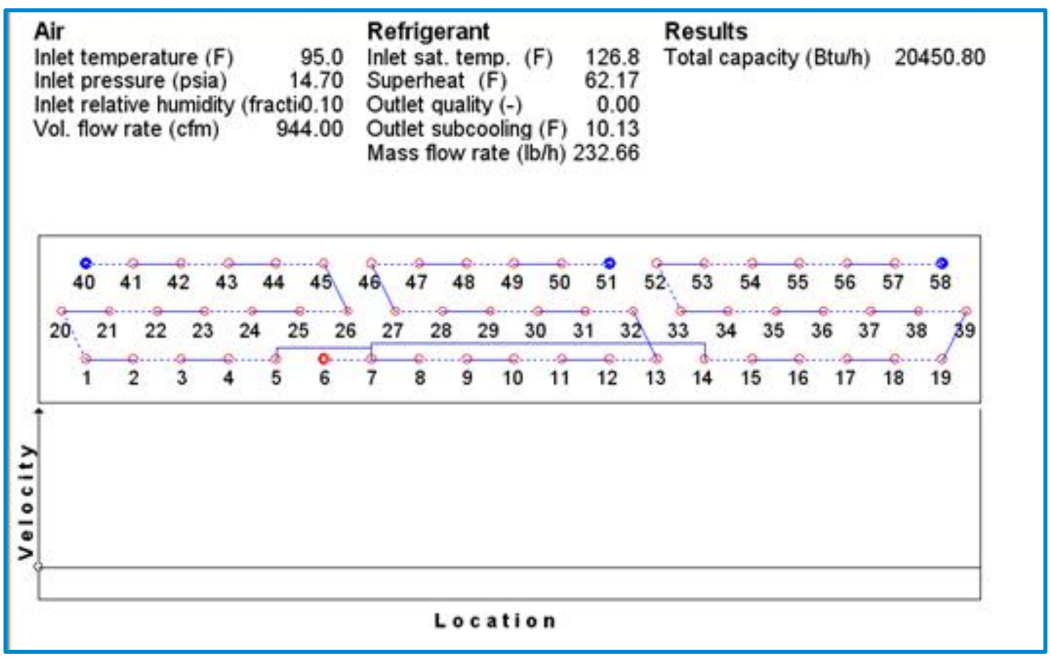


Figure 47 Window AC EvapCond Simulation – Proposed Condenser

### 3-4-6-3-3 Proctor Engineering Group Laboratory Experimentation

Preliminary development and evaluation of potential design improvements for the prototype air conditioners were performed at the Proctor Engineering Group laboratory. These tests were primarily focused on airflow, with the objectives of:

- Increasing the total airflow through the heat exchange coils
- Improving the uniformity of airflow across the face area of the heat exchange coils

For the window AC, testing also included an evaluation of the impact on EER of using condensate from the indoor section to help cool the outdoor heat exchange coil.

### *Window AC*

The Window AC airflow test apparatus consisted of plenum equipped with airflow measurement capability and a variable speed booster fan. The booster fan was controlled to produce zero static pressure at the air conditioner so that the air conditioner fans would operate as if discharging air into an open space with no resistance to airflow.

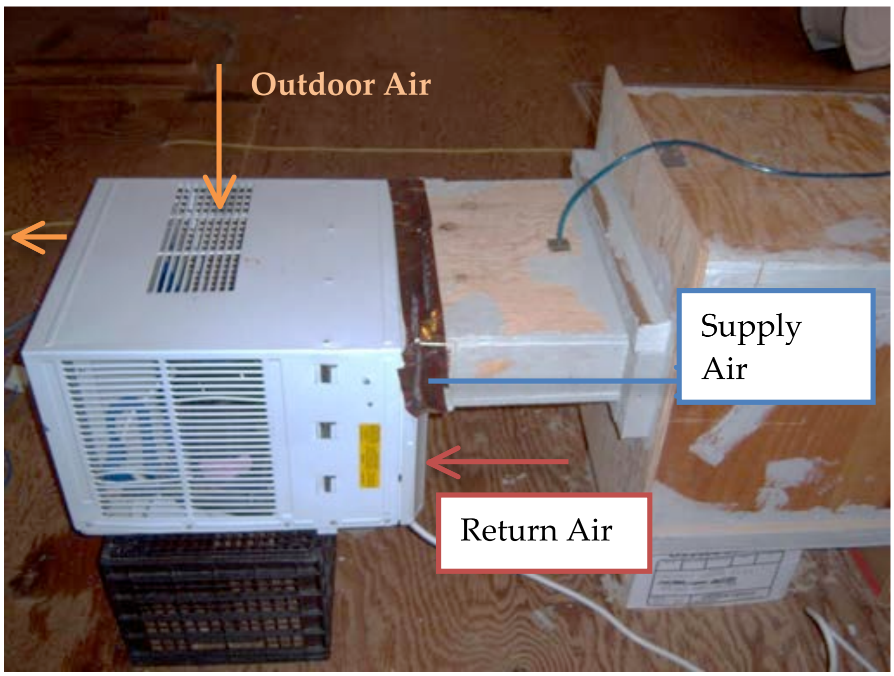


**Figure 48 Window AC Indoor Airflow Testing Apparatus**

**Table 16 Window AC Laboratory Instrumentation**

| Measurement | Sensor Type | Sensor Rated Accuracy |
|---|---|---|
| Air Flow | Series B Ductblaster | 3% |
| Static Pressure | Digital Manometer | 0.1 Pa |
| Fan Input Power | Watt Transducer | .5% |
| Motor Speed | Strobotachometer | .1% |

Airflow improvement concepts tested included:

- Eliminating sharp transitions in fan inlet air paths
- Eliminating sharp transitions in fan outlet air paths
- Larger indoor blower wheel
- Enlarged scroll area for indoor fan
- Increased fan motor speed
- Eliminate "splasher" wheel on condenser fan
- Reverse direction of condenser fan

The tests yielded the following results:

1. The window AC is space constrained due to the need to fit into a window. The US models, such as the one tested in the Proctor Engineering laboratory, are even smaller and more space constrained than the Saudi Arabia models. It is difficult to significantly alter the airflow characteristics or increase the heat exchanger face area within the size limitations of the standard window AC cabinet.
2. Eliminating sharp corners and smoothing the transitions in the indoor airflow path can improve airflow by 4% to 8%. In many designs this change is relatively simple and inexpensive to implement. For example, the US model tested in the Proctor Engineering lab would only require a modification to the shape of the molded Styrofoam fan housing.

**Figure 49 Indoor Fan Inlet with Smoothed Inlet Transitions**

Figure 50 Indoor Fan Housing with Smoothed Outlet Transitions

3. Reversing the direction of the outdoor fan so that it pulls air through the condenser instead of blowing air against the condenser can improve the distribution of airflow across the face area of the condenser coil.

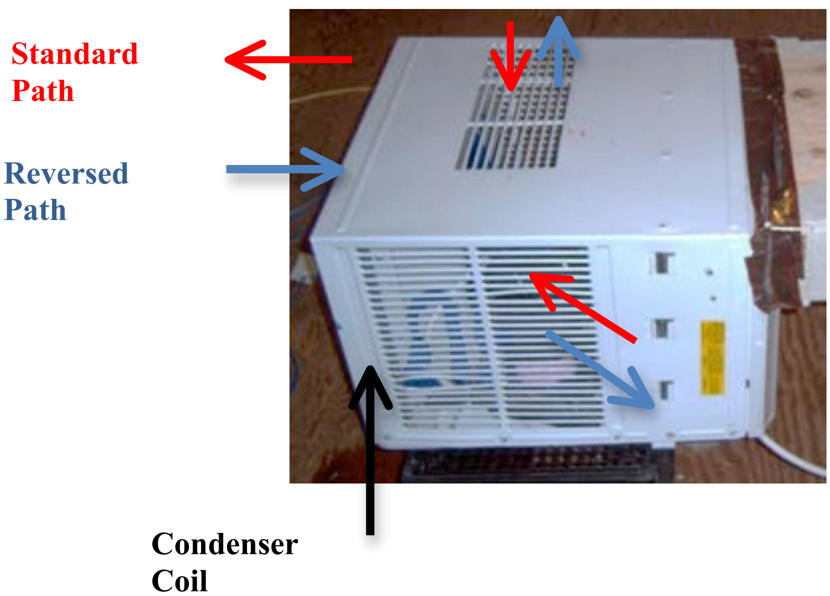


Figure 51 Reversed Condenser Fan Orientation

The original push-through design produced a region of very low airflow near the center of the coil, directly behind the center of the condenser fan. The pull-through orientation produced a uniform distribution across the majority of the coil face area.

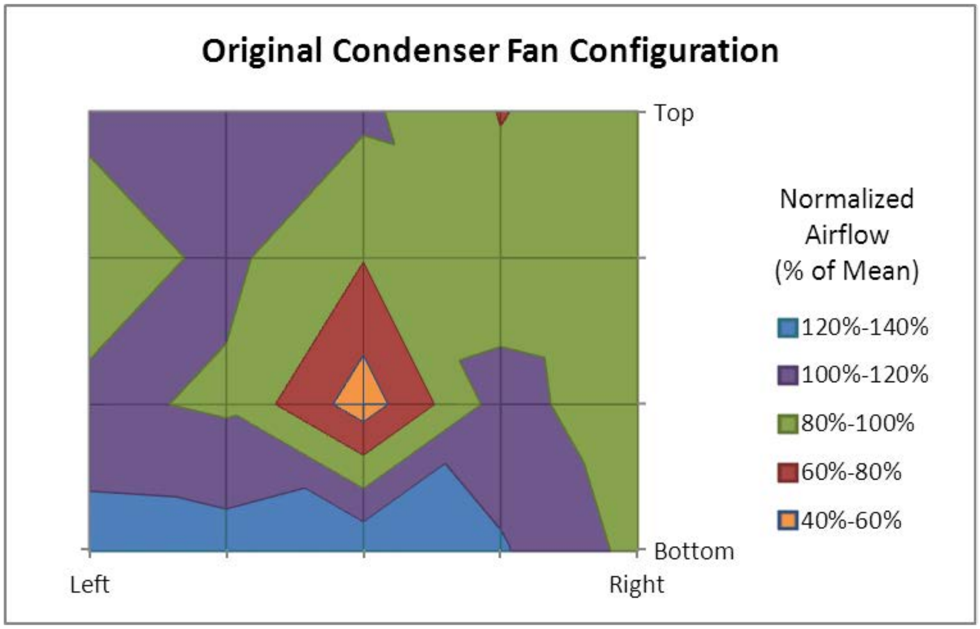


**Figure 52 Window AC Condenser Airflow Distribution – Original Configuration**

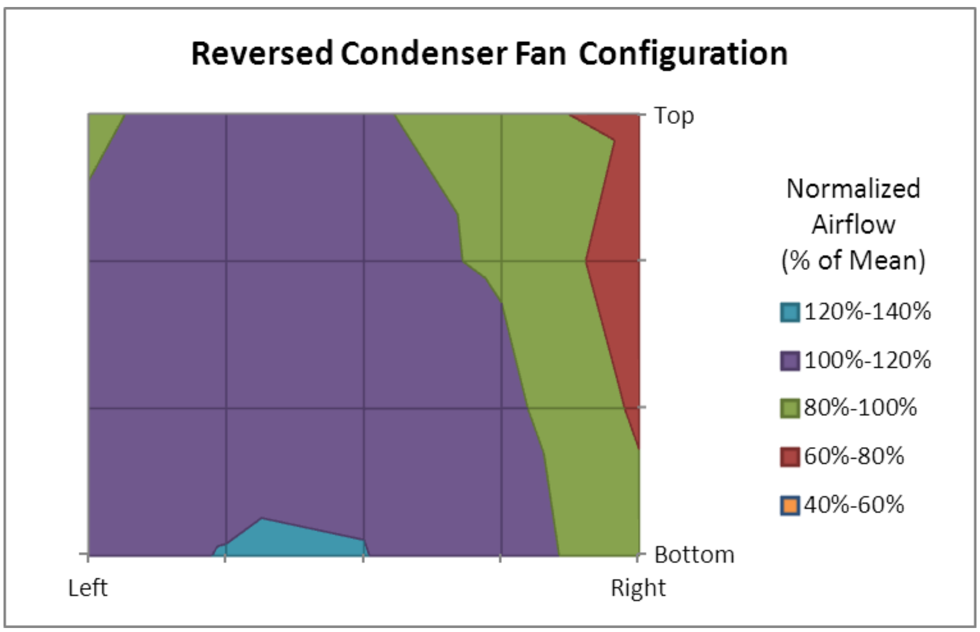


**Figure 53 Window AC Condenser Airflow Distribution – Reversed Configuration**

4. Splashing water on the condenser coil, as is standard practice in the window AC industry, can improve EER by 2% to 3%. This assumes the water reaches the coil. In the US model window AC tested in the Proctor Engineering laboratory, the standard configuration was such that water was pushed away from the splasher mechanism when the fan was operating and drained out of the unit instead of being splashed onto the coil. Manually splashing water onto the coil produced a 2% to 3% EER improvement.

5. Using condensate to evaporatively cool the superheated refrigerant leaving the compressor can improve EER by 2% to 3%, the same improvement seen in the standard configuration which splashes water onto the condenser coil. If the condenser fan direction is reversed as discussed in #3 such that it is no longer possible to splash water onto the condenser coil, then a similar benefit could be achieved by using the condensed water on the compressor discharge (hot gas) line instead.

### *Mini-Split AC*

Airflow for the mini split AC was measured using a vane anemometer across a grid of points marked on the heat exchange coil. A digital manometer was used to measure static pressure inside the indoor and outdoor sections.

Airflow improvement concepts included:

- Minimize airflow restrictions entering the indoor section
- Minimize airflow restrictions exiting the indoor section
- Improve exhaust airflow path of outdoor section
- Larger indoor fan
- Higher speed fan motors

Test results yielded the following results:

1. The indoor section of the mini split is very space constrained and there was little that could be done to improve airflow paths inside the indoor section.
2. The case for the indoor section includes a hinged cover that obstructs airflow into the evaporator coil. Removing the cover improved airflow by approximately 20% and reduced static pressure inside the indoor section by 35%.
3. The evaporator coil of the US model mini split unit was a 2 row wrap around design which provides greater face area and is less restrictive to airflow compared to the 3 row slab design found in the Saudi Arabia baseline mini split unit.

**Figure 54 US (left) and Saudi Arabia Baseline (right) Mini Split Evaporator Coils**

4. Providing a diffuser cone on the condensing unit fan exhaust increased airflow by 3% to 7% and reduced fan noise.

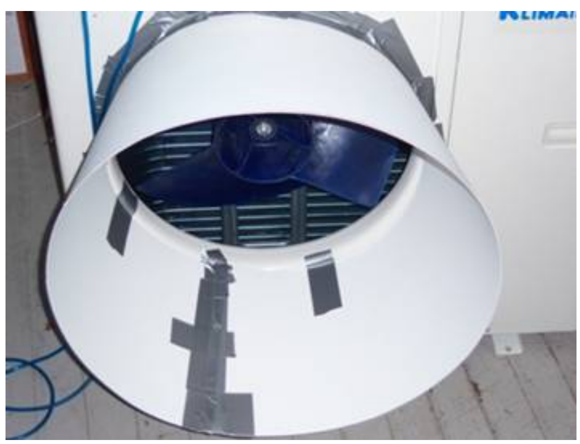

**Figure 55 Mini Split Condenser Fan Exhaust Diffuser**

3-4-6-3-4 Manufacturability and Design Finalization

Prior to developing the final design, an air conditioner manufacturer in Saudi Arabia was consulted to discuss energy performance enhancement options with respect to manufacturability and cost implications. Findings included:

- Building prototypes using microchannel coils is not feasible within the timeline of this project. Coil manufacturers indicated that suitable designs could be produced but a greater lead time is required than was possible during this project.
- There is significant manufacturer resistance to using microchannel evaporator coils due to concerns about condensate drainage.
- Using a pull-through condenser fan orientation instead of the standard push-through orientation is not feasible within the timeline of this project. In addition, there are concerns about dust being pulled into the coil in this configuration which would need to be addressed before implementation into production units.
- Increasing the heat exchanger fin density may be problematic due to greater propensity to collect dust. Further study to address these concerns would be needed prior to implementation onto production units. It was agreed that the fin density would not be increased over the baseline units.
- Higher efficiency compressors are available but at significantly increased cost. The best performing compressor identified during simulation modeling represents nearly a 100% cost increase over the baseline. It was agreed that compressors that projected to improve performance at minimal cost increase would be used in the final design. The final compressors selected represented a 4% cost increase (window) and probably cost decrease (mini split) relative to the baseline.
- Compressor options are limited by the need to use “Tropical” models designed to withstand Saudi Arabia’s extreme ambient temperatures. Compressor manufacturers view this as a niche market and produce a limited number of tropical models.
- It was agreed that several of the more innovative concepts could not be implemented in the prototype units due to time constraints. These concepts included:
    - Evaporative de-superheater
    - Evaporative precooler
    - Latent capture and re-delivery controls for dry climate regions
- In some cases the preferred heat exchanger design, as predicted by the EvapCond simulation, resulted in circuit configurations that presented manufacturability challenges. The coil designs were modified to select the best performing design that could be produced within the existing coil manufacturing capabilities.
- Higher indoor airflows raised concerns about noise and condensate drainage. While higher airflows can technically be achieved through larger fans or higher fan speeds, there are practical limits to the flow rates that could be implemented in production units.
- There is a greater than one year lead time to implement design changes that require importing new components into Saudi Arabia. This is influenced by

component manufacturer lead time, time required to import the components into the country, and the need to deplete inventories of current components.

- The manufacturer was highly interested in the simulation modeling process as a means to evaluate the performance impact of design changes and as a tool in the development of new products. The project team provided training in the use of the Mark VII and EvapCond simulation software to the manufacturer's design engineering staff for the window and mini split air conditioning product lines.

### 3-4-6-3-5 Baseline Unit Efficiency

R-22 was used as the refrigerant since only R-22 machines and components are sufficiently available for use in the Kingdom within the time frame of this project. R-22 will be phased out due to its effect on the ozone layer. It is anticipated that R-410A and R-407C will become the common refrigerants of the future. This study analyzes the probable difference in high temperature performance between R-22 and the two replacement refrigerants. The study suggests an approach to taking the performance differences into account when setting the performance standards for Saudi Arabia.

This program's market research showed that the most common residential unit is an 18,000 BTU per hour window air conditioner. The most common ductless mini-split is a 24,000 BTU per hour.

Baseline performance data were gathered from laboratory tests at Ikhtebar Company Ltd., an ETL verified test facility. For each test the electrical power, cycle state points, and flow were measured.

The instrumentation recorded the data in Table17 for the window and mini-split units.

**Table 17 Data List for Laboratory Tests**

| Location | Measurement | Measurement |
|---|---|---|
| Evaporator | Entering Air Dry Bulb | Leaving Air Dry Bulb |
| Evaporator | Entering Air Wet Bulb | Leaving Air Wet Bulb |
| Evaporator | Refrigerant Entering Temp. | Refrigerant Leaving Temp. |
| Evaporator | External Static Pressure | Airflow |
| Fan Motor | Current | Power |
| Fan Motor | RPM | |
| Condenser | Entering Air Dry Bulb | Entering Air Wet Bulb |
| Condenser | Refrigerant Condensing Temp. | Liquid Line Temp. |
| Condenser | External Static Pressure | Airflow |
| Compressor | Refrigerant Suction Temp. | Refrigerant Discharge Temp. |
| Compressor | Shell Top Temp. | Shell Bottom Temp. |
| Unit | Current | Power |
| Unit | Voltage | Power Frequency |

The instrumentation recorded the additional data in Table 18 for the mini-split units.

Table 18 Additional Mini Split Laboratory Data Points

| Location | Measurement | Measurement |
|---|---|---|
| Condenser Fan | Current | Power |
| Condenser Fan | RPM | |
| Condenser | Liquid Pressure | |
| Compressor | Refrigerant Suction Pressure | Refrigerant Discharge Pressure |

The tests were performed at three conditions:

1. SASO 2681/2007-T3 (46°C Ambient Dry Bulb, 24°C Ambient Wet Bulb, 29°C Indoor Dry Bulb, and 19°C Indoor Dry Bulb)
2. ISO5151-T1(46°C Ambient Dry Bulb, 24°C Ambient Wet Bulb, 27°C Indoor Dry Bulb, and 19°C Indoor Dry Bulb)
3. 46°C Ambient Dry Bulb, 24°C Ambient Wet Bulb, 27°C Indoor Dry Bulb, and 19°C Indoor Dry Bulb

#### 3-4-6-3-6 Baseline Unit Modeling

Test data and the physical parameters were used to create a computer model of the baseline units. The Oak Ridge National Lab Heat Pump Design Model (HPDM) Mark VI was used for modeling the baseline units (ORNL 2002). The model was calibrated to baseline test data. These models were the starting points for the design process. The simulation was used to model the performance of the units at T1 and T3.

The modeling started with the performance (Capacity and EER) from the test data. The known physical parameters of the units and the measured superheat and subcooling were entered into the model. The manufacturer's supplied compressor map was used in the model.

The model was tuned using the coil heat transfer and pressure drop adjustment factors so it closely matched the measured internal pressures, temperatures, flows, gross capacities, and sensible heat ratios from the test data. Finally, the compressor power and mass flow rate adjustment factors were adjusted to match the EERs at T1 and T3.

The primary adjustment points were the EERs and capacities at T1 and T3.

#### 3-4-6-3-7 Component Investigation and Selection

The team researched a broad range of potential component designs for use in the KSAAC units. The potential candidates were evaluated for cost, performance, availability, maintenance issues, durability and reliability.

The components and their effects on the cost and performance of the designs were evaluated using; manufacturers' data and research reports; published technical reports; modeling of refrigerant cycles, as well as EVAP-COND (Domanski and Payne 2002).

#### 3-4-6-3-8 Modeling KSAAC Units

These baseline models were the starting points for the design process. The design point for this project was: 46°C outdoor temperature, 29°C return plenum dry bulb temperature, and 19°C return plenum wet bulb temperature.

Through iteration the input parameters were adjusted to provide designs that met the performance criteria of this project. Tradeoffs were made between design options (such as larger condenser coils vs. larger evaporator coils) based on the relative cost effectiveness of the options. Hundreds of iterations were performed in the design process. These iterations included step-by-step interactive incremental changes, and on occasion, major jumps in most of the input parameters. The occasional major jumps reduce the likelihood of producing local optimums that have less efficiency than other optimums discernible when the model approaches from another “angle”.

### *Design Criteria and Considerations*

The main design criteria were to:

- Improve the Benefit Cost Ratio for all Affected Entities
- Reduce Peak Electrical Consumption by 15% to 25%
- Energy Saving of 10% to 20%
- Initial Cost increase 5% to 25% of Baseline
- Produce a Buildable and Marketable Design

The following considerations were included in the process:

1. Design for easy adoption
    - component availability,
    - smallest effective deviation from existing practice,
    - potential for mainstreaming (avoid technologies that manufacturers shy away from)
2. Proven performance
    - in previous tests,
    - in modeling
3. “Drop in” replacement for baseline unit
    - cooling capacity,
    - footprint

### 3-4-6-3-9 KSAAC Assembly and Development Tests

Proctor Engineering and AMAD staff worked at an air conditioner manufacturing facility in Saudi Arabia for two weeks to build and test the prototype units. An incremental process of implementing a specific design modification and testing the resulting performance change was used.

#### *Window Unit Airflow Modifications*

Eliminating sharp corners to the inlet to the indoor fan of the window AC increased the indoor airflow by 6%. This is a relatively simple and inexpensive design change, but the extent to which it can be implemented is limited by other design features. The U.S. model window AC tested in the Proctor Engineering laboratory was able to be smoothed around the entire circumference of the fan inlet because the entire inlet is molded from Styrofoam. The Saudi Arabia unit has a sheet metal inlet and some models require an electric resistance heater to be hung in front of the fan inlet. These design factors limited the inlet smoothing to two sides as shown below.

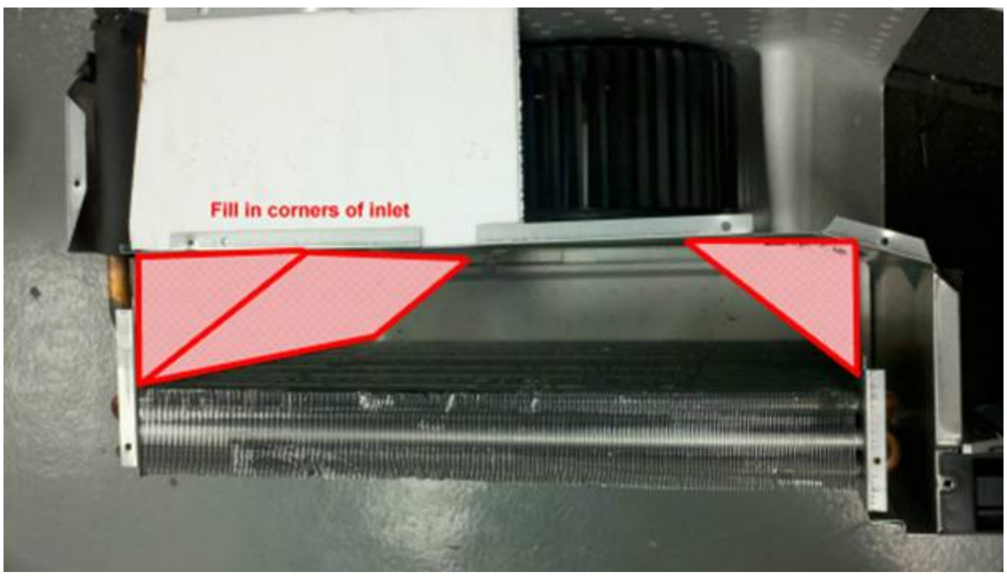


**Figure 56 Window AC Prototype Indoor Fan Inlet Modification**

Sharp corners at the fan outlet were similarly smoothed but produced no measurable change in airflow.


Figure 57 Window AC Prototype Indoor Fan Outlet Smoothing

The outlet to the indoor fan of the window air conditioner was enlarged as shown below. This produced no measurable change in airflow, but is still a desirable design change because it also serves to shape the fan inlet on this side of the coil.

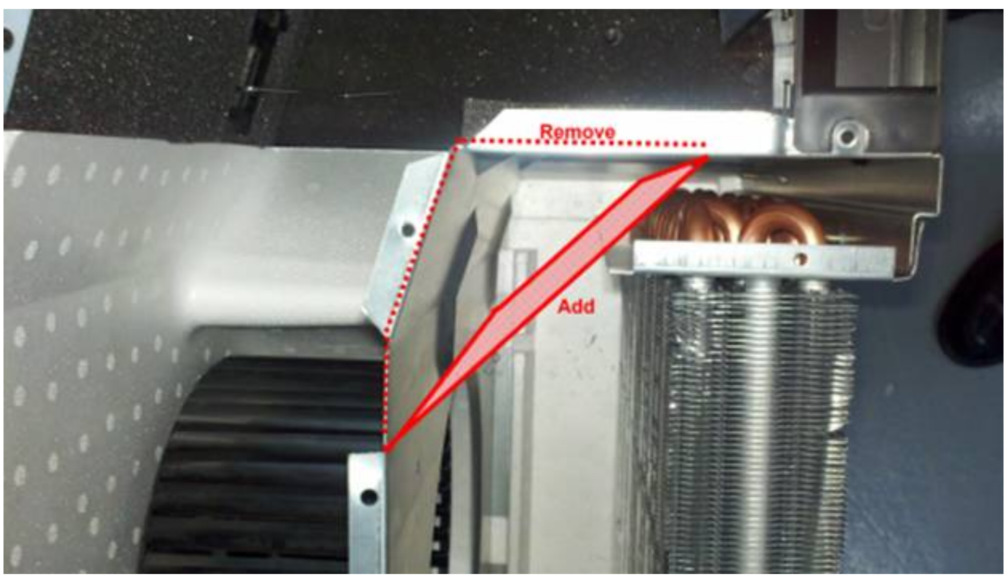


Figure 58 Window AC Prototype Indoor Fan Outlet Modification

Air inlet area to the condenser was enlarged to increase airflow through the condenser coil. This modification increased airflow by 2% to 6% over the baseline.

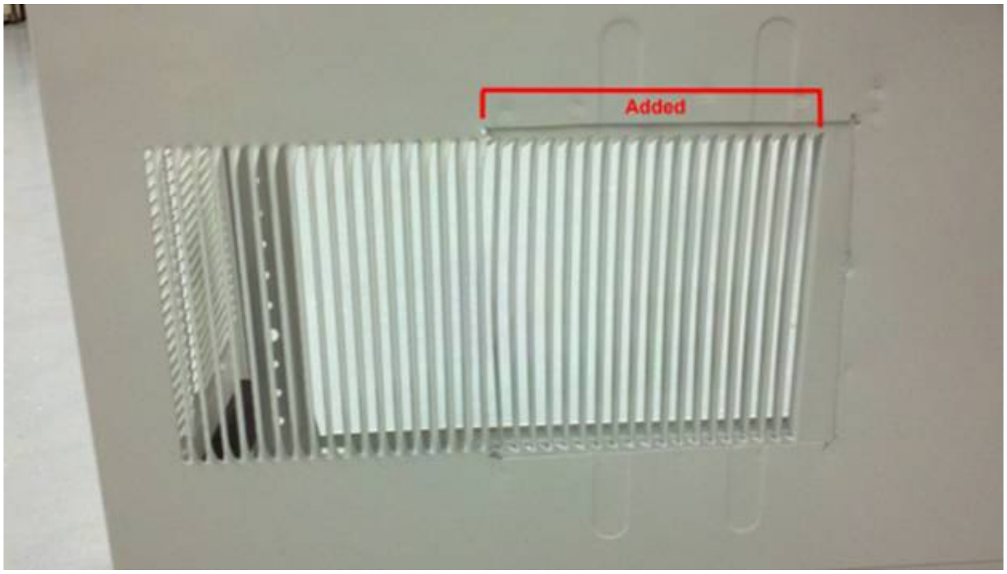


Figure 59 Window AC Prototype Enlarged Condenser Air Inlet Area

### *Window Unit Heat Exchanger Modifications*

Modified evaporator and condenser heat exchangers were used in the window air conditioner prototype. The evaporator coil was modified slightly from the original design in an attempt to improve the distribution of refrigerant flow through the circuits with respect to airflow distribution across the coil. The condenser coil was modified from a 2 row to a 3 row design and a new circuit layout was developed using the EvapCond simulation.

### *Window Unit Compressor Selection*

The team worked with compressor manufacturers and air conditioner manufacturers to select the compressors for the prototypes. Reciprocating compressors have traditionally been preferred for use at high ambient temperatures because the cool suction gas is used to cool the compressor motor. (Singh & Helena 2011). The team investigated available compressors, their efficiencies, their efficiency at high condenser temperatures, and their costs to find a least cost route to improved efficiency.

### *Mini-Split Unit Airflow Modifications*

Eliminating a sharp corner to the fan inlet of the indoor section of the mini split air conditioner improved airflow by 3%

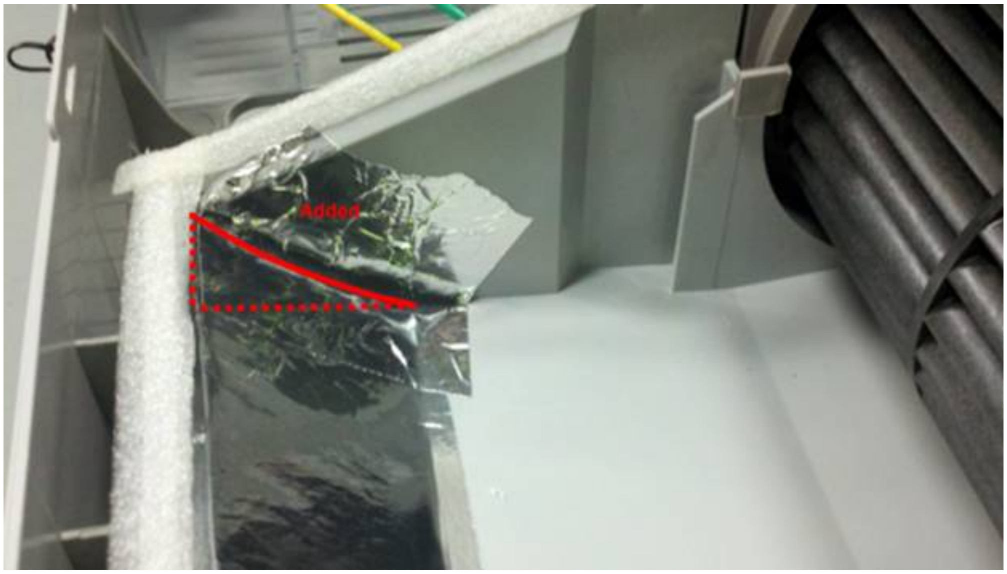


Figure 60 Mini Split AC Prototype Indoor Fan Inlet Modification

The original design of the baseline mini split condenser grille was overly restrictive to airflow. Removing the grille increased airflow by 15% and reduced fan noise. A modified and less restrictive grille was used in the prototype.


Figure 61 Mini Split AC Prototype Less Restrictive Condenser Grille

### *Mini Split Heat Exchanger Modifications*

The evaporator coil of the mini split air conditioner was enlarged by 17% by the addition of a section containing one refrigerant circuit. The original coil was repositioned to accommodate the new section.


**Figure 63 Mini Split AC Prototype Evaporator Coil Enlarged**

A similar approach is used by some mini split manufacturers to increase the evaporator coil face area. For example, the U.S. model mini split tested in the Proctor Engineering laboratory used a four section coil.

**Figure 62 US Model Mini Split Evaporator Coil**

The condenser coil of the mini split air conditioner was modified from a 26 tube 2 ½ row design to a 34 tube 3 row design. The heat exchanger circuit configuration was optimized in the EvapCond simulation. Since the final design resulted in a taller coil, the condenser fan was repositioned to improve airflow distribution across the coil. The increase in coil face area is approximately the same as if the coil was extended horizontally around the compressor section. Extending the coil to wrap around the compressor may be a preferable configuration for a production design, but was not possible in the prototype due to time limitations and the need to reposition the compressor and electrical components.

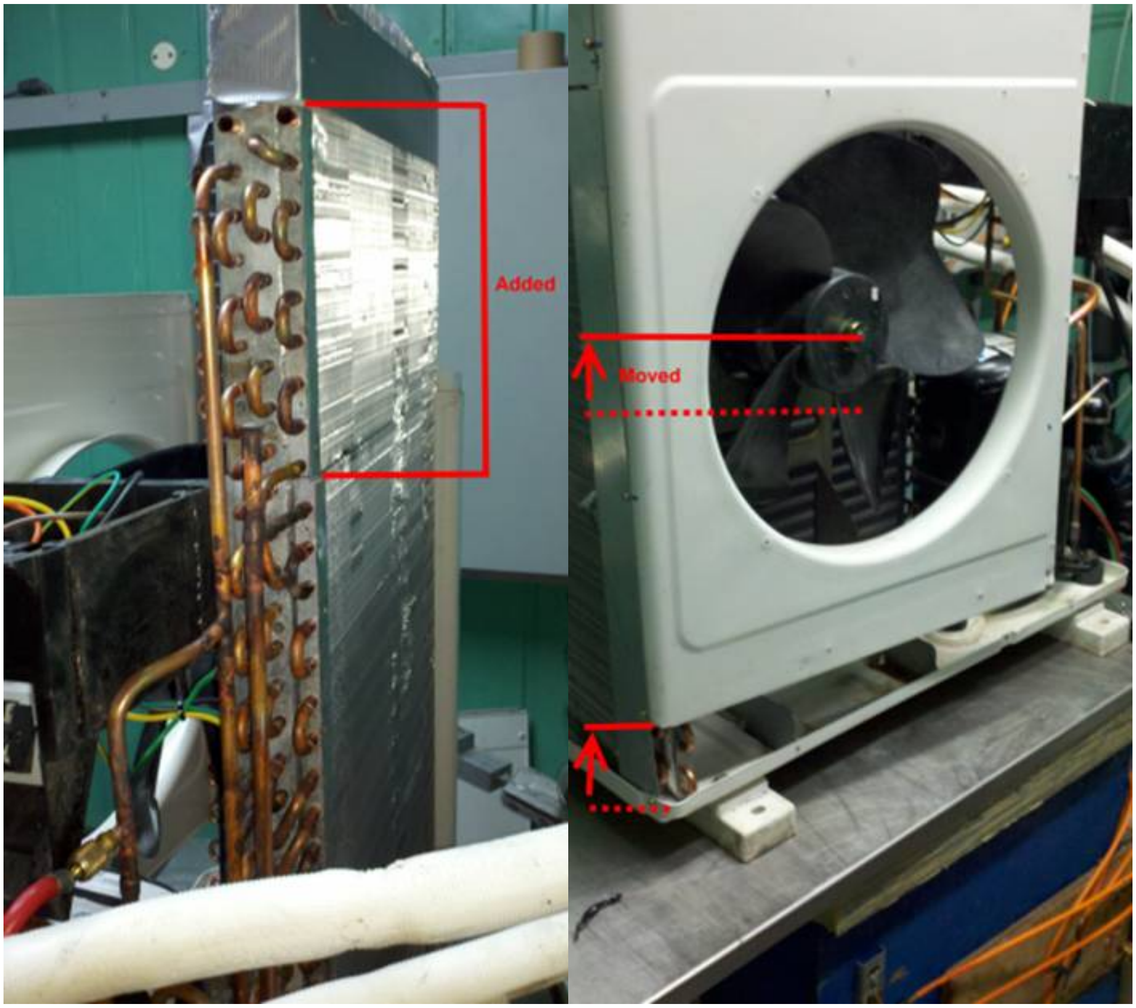


Figure 64 Mini Split AC Prototype Condenser Coil Height Increased and Fan Repositioned

#### ***3-4-6-4 Laboratory Prototype Testing Results***

3-4-6-4-1 Airflow Testing

*Window Unit*

The final configuration of airflow improvements plus the more restrictive 3 row condenser coil resulted in indoor airflow 2% higher than the baseline and outdoor airflow 4% lower than the baseline.

*Mini-Split Unit*

The changes in the Fan Inlet of the indoor unit shown above resulted in a 3% improvement in indoor airflow without any additional changes.

### 3-4-6-4-2 Performance Testing

#### *Window Unit*

Initial performance testing indicated capacity and efficiency lower than expected and temperatures on the individual circuits in the evaporator coil indicated refrigerant flow maldistribution resulting in liquid refrigerant exiting the coil in one circuit while superheated refrigerant exited other circuits. The evaporator coil was replaced with the baseline coil and the unit was re-tested.

EER and capacity performance did not improve after replacement of the evaporator coil and it was decided to replace the compressor. The original compressor specified for the prototype was a one-of-a-kind sample and no backup was available to replace it. A slightly higher rated and higher capacity model within the same product line was available and was selected as a replacement.

Capacity improved slightly with the replacement compressor, but EER remained below expectations. Further investigation identified two issues:

1) Despite being from the same product line as the original compressor, and despite having a slightly higher EER rating, the performance curves for the new compressor indicate significantly lower efficiency. At conditions similar to the operating conditions at T1 the performance curves for the new compressor indicate 1% higher capacity and 23% higher watt draw than the original compressor specified for the prototype. It is not known if the performance curves are in error or if the compressor rating is in error for either compressor.

2) Disassembly of the window air conditioner revealed that the condenser coil had been built as a mirror image of the intended design. The resulting coil configuration resulted in 10% lower capacity when tested in the EvapCond model. It is expected that this had a significant impact on the performance of the window AC prototype.

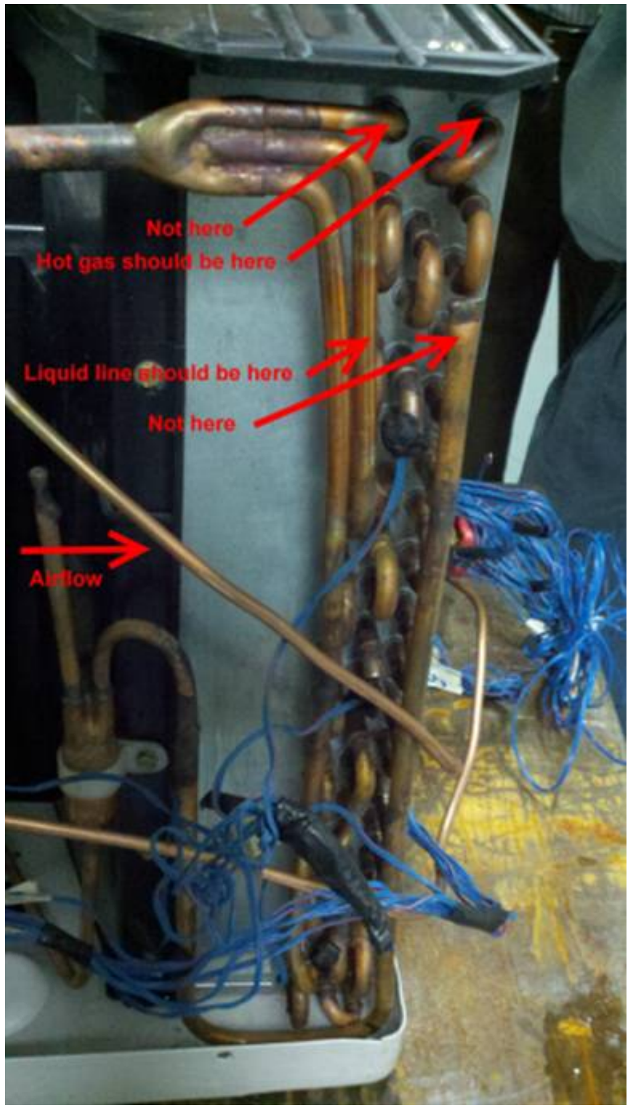


Figure 65 Window AC Prototype Condenser Coil Orientation Problem

The condenser coil was rebuilt and the design iterations continued.

A higher efficiency compressor from a different product line was installed into the unit. This compressor proved to be significantly noisier than the baseline compressor. At the same time the capillary tubes and distributor were replaced since there were indications of a partial blockage.

The results of the laboratory testing continued to fall short of the goal of a 10% or larger improvement in EER. Zamil makes a window air conditioner similar to the baseline unit with an even higher efficiency (and more expensive) compressor. For the economic analysis that unit is used to project the manufacturing costs compared to baseline. The efficiencies of the prototype unit and the NCP18 unit are shown in xxx.

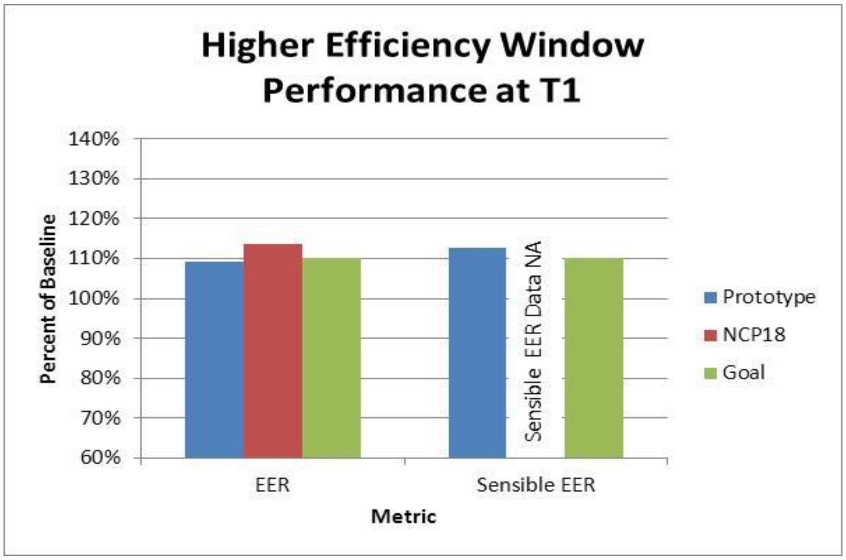


Figure 66 Window Units' Performances at T1

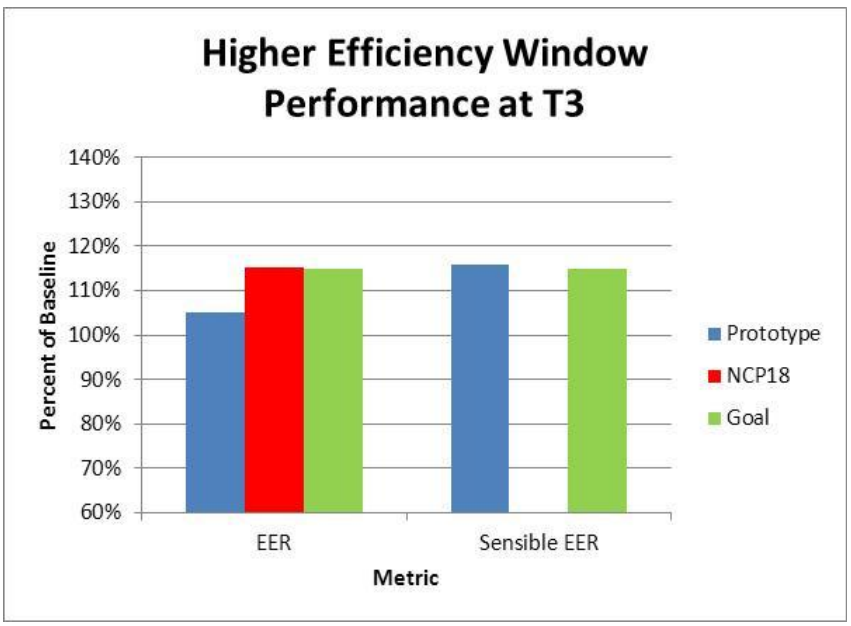


Figure 67 Window Units' Performances at T3

### *Mini-Split Unit*

Two prototype configurations of the mini-split were tested in the laboratory. These two configurations were identical except that Prototype 2 had increased the indoor coil airflow from 568 CFM to 705 CFM.

The mini-split prototypes exceeded the goals of the program as shown in the figures below. Both prototypes (with and without increased evaporator airflow) meet the goal of at least 10% increase in EER at T1. Most importantly for Hot Dry Climates, they both significantly exceed the goal of increased Sensible EER with improvements of 19% and 31%.

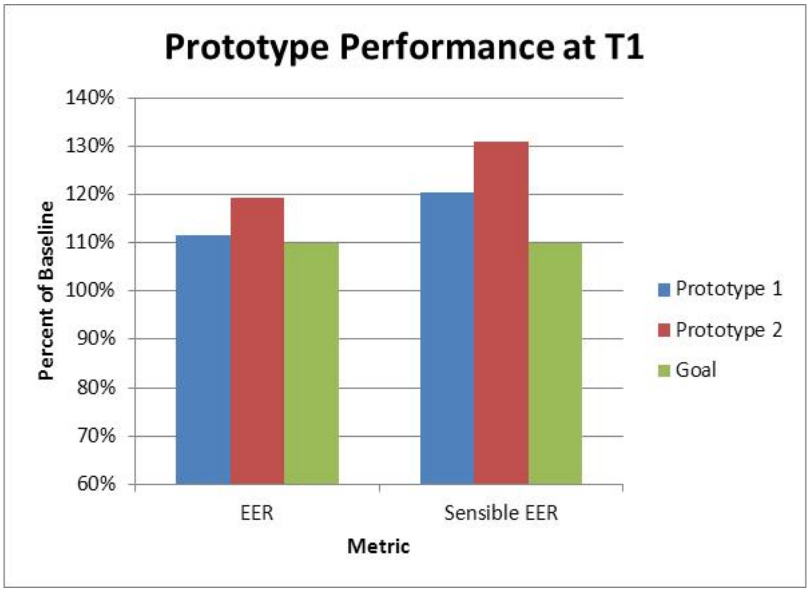


Figure 68 Prototype Mini-splits' Performance at T1

Both prototypes (with and without increased evaporator airflow) meet the goal of at least 15% increase in EER at T3. Most importantly for Hot Dry Climates, they both significantly exceed the goal of increased Sensible EER with improvements of 27% and 36%

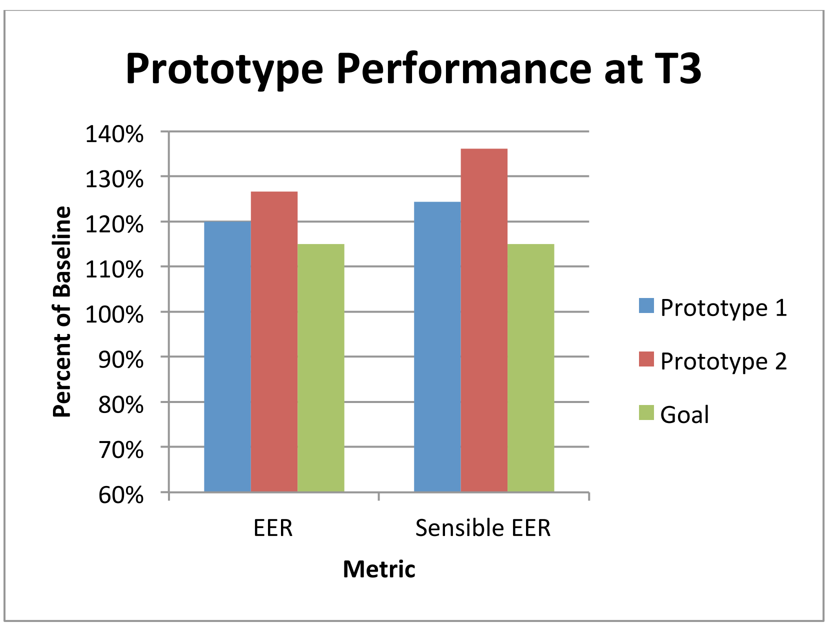


Figure 69 Prototype Mini-splits' Performance at T3

Both prototypes (with and without increased evaporator airflow) have increased capacities at T3. Most importantly for Hot Dry Climates, they have increased Sensible capacity by 5% and 17% respectively. In production the size of the compressors can be reduced to bring the capacity closer to the baseline and potentially achieve higher efficiency in the process.

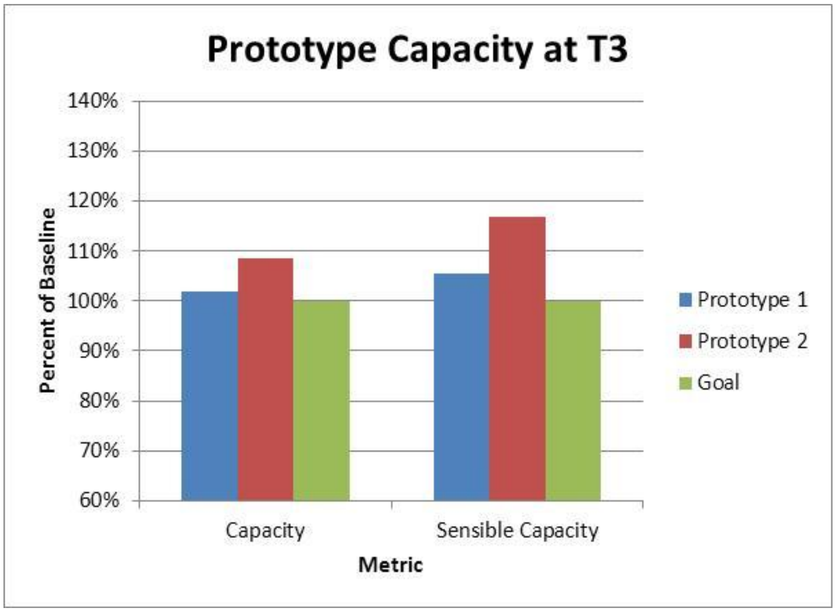


Figure 70 Prototype Mini-splits' Capacities at High Temperature

### 3-4-7 Economics and Life Cycle Cost

The economics of Saudi air conditioner manufacturing, sales, and operation involve the costs borne by all participants. When a change in minimum efficiency standards are proposed, the analysis attempts to take into account all the known increases in cost as well as all the benefits of energy (and cost) savings. Some benefits are difficult to reduce to an economic value. These benefits include such items as pollution reduction. Some of these benefits are addressed in other sections of this report.

The life cycle cost of an air conditioner can be viewed from a variety of perspectives. From the customer's perspective, it consists of the initial cost of the unit plus the cost of maintenance, repair, and energy use. Due to the low subsidized electrical rates in the Kingdom the lifecycle costs of air conditioners from the consumer perspective are unusually low.

From the perspective of the Kingdom, the life cycle costs include the cost of electricity generation, transmission, and distribution. These costs are substantially higher than the costs seen by the consumer. As a result the lifecycle costs of air conditioners are high because of the large energy consumption by each unit as well as the high costs of transmission and distribution needed for peak days.

#### *3-4-7-1 Potential Savings*

The energy consumption of an air conditioner is dependent on the amount of time it is used (Run hours), its capacity (BTUs per hour), its efficiency at the operating conditions (EER), as well as auxiliary energy use, such as fan run time when the compressor is off. The steady state energy consumption of the air conditioner is expressed as:

$$EU_T = Cap_T / EER_T$$

where,

$$EU_T = Energy\ Use\ (Watts\ per\ hour)\ at\ Outside\ Temperature\ T$$

$$Cap_T = Capacity\ (BTUs\ per\ hour)\ at\ Outside\ Temperature\ T$$

$$EER_T = Energy\ Efficiency\ Ratio\ (BTUs\ per\ Watt)\ at\ Outside\ Temperature\ T$$

It is clear from the above that increases in capacity will increase the amount of energy use if the air conditioner runs for the same amount of hours and at the same efficiency,

The goals of an energy savings program would be to increase the efficiency of the air conditioners, reduce the number of run hours, and maintain or reduce the total capacity of air conditioners within a residence.

The Unit Average Consumption Section of this report derived three estimates of the annual energy consumption of average sized residential air conditioners in the Kingdom. These scenarios are summarized in Table 19.

**Table 19 Air Conditioner Average Consumption for Residential ACs in Saudi Arabia**

Scenario A

| **Region** | **Central** | **Western** | **Eastern** | **Southern** |
|---|---|---|---|---|
| Window kWh | 3016 | 1916 | 3386 | 160 |
| Split kWh | 3581 | 2359 | 4232 | 182 |

Scenario B - Higher Energy Use

| Region | Central | Western | Eastern | Southern |
|---|---|---|---|---|
| Window kWh | 3278 | 2083 | 3680 | 173 |
| Split kWh | 3893 | 2564 | 4600 | 198 |

Scenario C - Highest Energy Use

| Region | Central | Western | Eastern | Southern |
|---|---|---|---|---|
| Window kWh | 3540 | 2250 | 3975 | 187 |
| Split kWh | 4204 | 2769 | 4968 | 214 |

The unit average consumption estimate is a sum of the air conditioner's usage over a year under all temperature conditions.

### *3-4-7-2 Cost Effectiveness*

This analysis compares the estimated cost increases at the manufacturer to the estimated savings at the customer level and estimated savings at the primary fuel level. The cost increases at the manufacturer are based on units similar to the prototype units tested as well as existing higher efficiency air conditioners produced in Saudi Arabia.

### *3-4-7-3 Cost Increase at the Manufacturer*

The KSA Manufacturer Survey heat exchange coil cost estimates are based on limited results and appear lower than would be typical for the average manufacturer. The DOE values indicate heat exchange coil costs comprise 12% to 19% of the total manufacturer cost, which is higher than reported on the KSA survey.

**Table 20 Cost Increase Estimates for Prototype Design Modifications**

| | **Manufacturer Cost Increase (% of total cost)** | **Basis** |
|---|---|---|
| **Window AC** | | |
| Airflow path improvements - indoor | 1% | Estimate based on minor increase in material and assembly labor |
| Airflow path improvements - outdoor | 0% | Design change only, no additional hardware or material required |
| Additional condenser row | 3% | US DOE Rulemaking TSD, incremental cost for adding additional condenser row to 24,000 BTU/h window air conditioner |
| Higher EER compressor | 17% to 26% | KSA Manufacturer Survey and workshop presentations |
| **Mini Split AC** | | |
| Airflow path improvements - indoor | 0% | Design change only, no additional hardware or material required |
| Airflow path improvements - outdoor | 0% | Design change only, no additional hardware or material required |
| Enlarge evaporator coil | 2% | Estimate based on US DOE TSD for incr. Evaporator coil |
| Enlarge condenser coil | 3% | Estimate based on US DOE TSD for incr. Condenser coil |
| Enlarge outdoor cabinet | 4% | Estimate based on material cost increase of larger chassis |
| Reduce compressor capacity | 0% | No cost increase |

The window unit (RAC) space constraints necessitated upgrading the most costly component, the compressor, to achieve the project efficiency goals. Other design modifications to the RAC and Mini Split ACs can be implemented with minor increases in per unit cost. In particular, modifications to improve the airflow paths generally require a design and tooling change, with no increase in hardware cost.

**Table** 21 displays the estimated baseline costs as well as the estimated cost increases at the manufacturer and for the consumer. These estimates are for the most common (18,000 BTUh) window unit and the most common (24,000 BTUh) mini split. The estimated cost increases are displayed for percentage increases in EER at T1 and T3.

**Table 21 Baseline Costs and Incremental Costs by EER**

| | Window | | Mini Split | |
|---|---|---|---|---|
| | Manufacturer | Customer | Manufacturer | Customer |
| Baseline Cost | $ 147.00 | $ 329.28 | $ 328.00 | $ 734.72 |
| | | Incremental Costs | | |
| +5% Δ EER | $ 14.70 | $ 32.93 | $ 6.56 | $ 14.69 |
| +10% Δ EER | $ 32.34 | $ 72.44 | $ 13.12 | $ 29.39 |
| +15% Δ EER | $ 47.04 | $ 105.38 | $ 22.96 | $ 51.43 |
| +20% Δ EER | $ 73.50 | $ 164.64 | $ 36.08 | $ 80.82 |
| +25% Δ EER | | | $ 52.48 | $ 117.56 |
| +30% Δ EER | | | $ 98.40 | $ 220.42 |
| | | | | |

### *3-4-7-4 Lifetime Energy Cost Savings*

The lifetime energy cost savings for window and mini split units are displayed in Table 22. The average lifetime is estimated as 10 years for the Window unit and 15 Years for the Mini Split.

Table 22 Lifetime Energy Costs by EER

| Δ EER | Window Lifetime Savings | | | Mini Split Lifetime Savings | | |
|---|---|---|---|---|---|---|
| Scenario A | Customer | Primary Fuel | Total | Customer | Primary Fuel | Total |
| 5% | $ 28.31 | $ 107.41 | $ 135.72 | $ 51.77 | $ 196.42 | $ 248.19 |
| 10% | $ 54.04 | $ 205.06 | $ 259.10 | $ 98.83 | $ 374.99 | $ 473.82 |
| 15% | $ 77.54 | $ 294.21 | $ 371.75 | $ 141.79 | $ 538.03 | $ 679.82 |
| 20% | $ 99.08 | $ 375.94 | $ 475.01 | $ 181.18 | $ 687.48 | $ 868.66 |
| 25% | $ 118.89 | $ 451.13 | $ 570.02 | $ 217.42 | $ 824.98 | $ 1,042.39 |
| 30% | $ 137.18 | $ 520.53 | $ 657.71 | $ 250.86 | $ 951.90 | $ 1,202.76 |
| Scenario B | | | | | | |
| 5% | $ 30.77 | $ 116.75 | $ 147.51 | $ 56.27 | $ 213.51 | $ 269.78 |
| 10% | $ 58.74 | $ 167.16 | $ 225.90 | $ 107.42 | $ 407.62 | $ 515.04 |
| 15% | $ 84.28 | $ 239.84 | $ 324.11 | $ 154.13 | $ 584.84 | $ 738.97 |
| 20% | $ 107.69 | $ 306.46 | $ 414.14 | $ 196.94 | $ 747.30 | $ 944.24 |
| 25% | $ 129.22 | $ 367.75 | $ 496.97 | $ 236.33 | $ 896.76 | $ 1,133.09 |
| 30% | $ 149.10 | $ 424.33 | $ 573.43 | $ 272.69 | $1,034.72 | $ 1,307.41 |
| Scenario C | | | | | | |
| 5% | $ 33.23 | $ 126.10 | $ 159.33 | $ 60.77 | $ 230.58 | $ 291.35 |
| 10% | $ 63.44 | $ 240.73 | $ 304.17 | $ 116.01 | $ 440.21 | $ 556.22 |
| 15% | $ 91.03 | $ 345.39 | $ 436.42 | $ 166.45 | $ 631.60 | $ 798.05 |
| 20% | $ 116.31 | $ 441.33 | $ 557.64 | $ 212.69 | $ 807.04 | $ 1,019.73 |
| 25% | $ 139.57 | $ 529.60 | $ 669.17 | $ 255.23 | $ 968.45 | $ 1,223.68 |
| 30% | $ 161.04 | $ 611.08 | $ 772.12 | $ 294.49 | $1,117.45 | $ 1,411.94 |

The lifetime energy cost savings are calculated at the customer level and at the primary fuel level. As shown in Figure 71, efficiency changes for the window (RAC) units are not cost effective for the consumer at an average AC kWh cost of 9.5 Halala. The lifetime energy savings will not pay for the initial cost increase in the air conditioner.

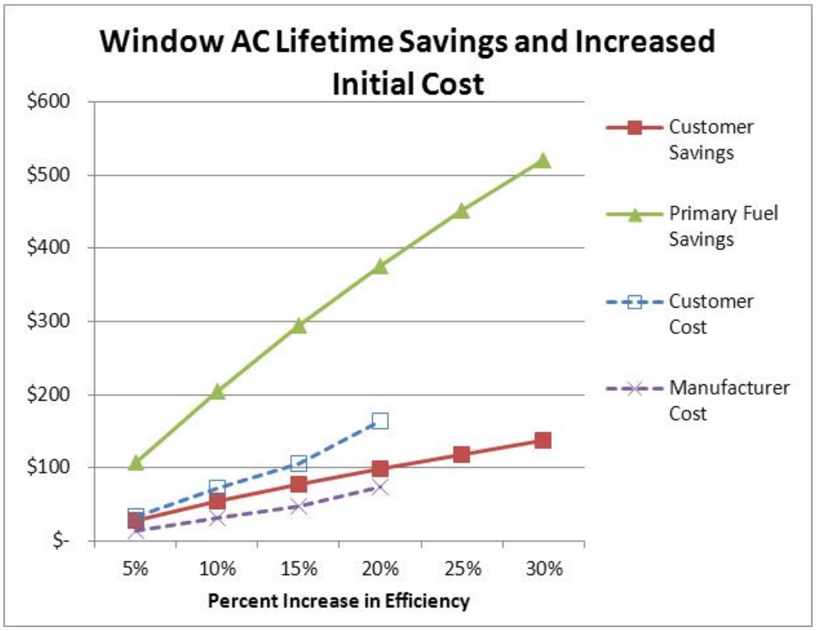


Figure 71 Window AC Lifetime Savings and Increased Initial Cost

When the lifetime energy savings at the primary fuel level and compared to the initial costs at the manufacturer level, upgrades to the window units are cost effective and currently practical up to a 15% efficiency increase.

As shown in Figure 72, efficiency changes for the mini split units are cost effective for the consumer but a 25% efficiency increase has a simple payback of 8.1 years. This type of payback is not usually attractive to a consumer used to low prices.

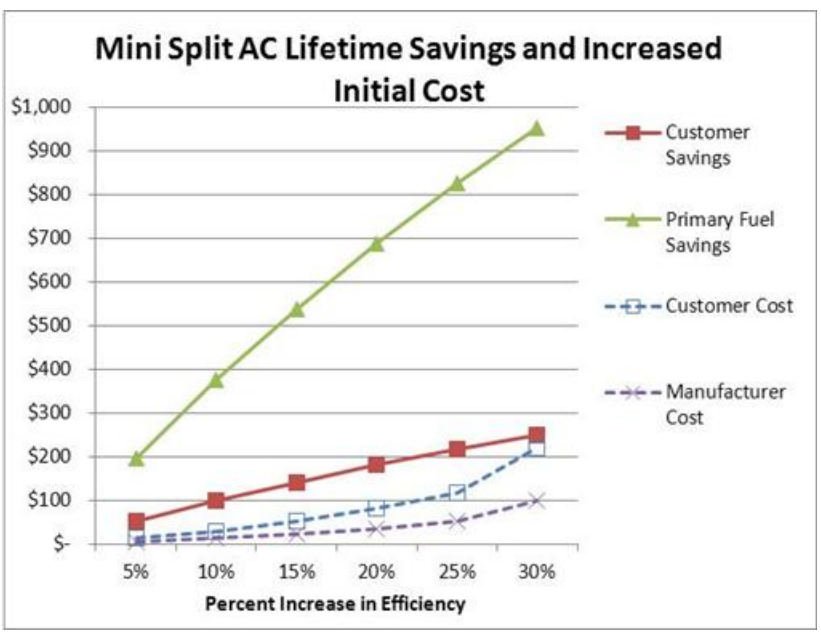


Figure 72 Mini Split AC Lifetime Savings and Increased Initial Cost

When the lifetime energy savings at the primary fuel level and compared to the initial costs at the manufacturer level, upgrades to the mini splits are cost effective and currently practical up to a 25% efficiency increase.

### 3-4-8 Interaction of Economics and Standards Enforcement

There is a strong connection between standards enforcement and the economics of air conditioner manufacturing and sales. Without strong and persistent standards enforcement, low cost substandard equipment enters the market. These pieces of equipment draw customers away from the higher performing equipment thus reducing the monetary incentive for compliance.

### 3-4-9 Manufacturer Impact Analysis

Significant changes in enforced minimum air conditioner efficiencies as suggested in this study are likely to put pressure on manufacturers that may cause significant realignment within the marketplace. The easiest improvement in efficiency comes at the highest cost – upgrading the compressors. The supply of higher efficiency compressors of the proper size and configuration is currently limited.

Some manufacturers may produce higher efficiency air conditioners at a lower cost by making changes that are considered unacceptable to Saudi manufacturers. An example would be heat exchangers with more fins per inch.

The actual impact of a 15% increase in minimum window AC efficiency and a 25% increase for mini-splits is unknown, but the potential for unintended market realignment is present.

The economics suggest that a realignment of costs might be beneficial to the Kingdom. Given the large subsidy at the primary fuel level as well as the subsidy associated with transmission and distribution, it would be economically possible to shift some of the subsidy money to improving the efficiency of window and mini split air conditioners for the short term. In some countries this type of shift is supported by tax incentives. Higher efficiency air conditioners are also encouraged in the United States by utility company incentives.

Incentives can be applied at different points in the distribution chain. Incentives applied downstream, at the retail customer level, are used to increase the customer demand for higher efficiency air conditioners. This approach has the least leverage on the final cost to the customer.

Incentives can be applied upstream, at the level of the manufacturer or importer. At that level the incentives have the most leverage having the possibility of maintaining the same retail cost to the customer by covering the manufacturer's increase in cost. Given the distribution chain markup, the incentives could be less than half what they would be at the retail level to obtain the same effect. The distribution chain multiplier is 2.24 so the manufacturer incentive could be 1 / 2.24 what the customer incentive would have to be.

We would not suggest customer level incentives. Given that this process is to change the minimum efficiency levels, it is not necessary, nor desirable to increase the customer demand for air conditioners. There are further drawbacks associated with providing incentives or marketing at the customer level. Studies have shown that when customers obtain higher efficiency products, some of the customers take advantage of the higher efficiency by using the product more, buying a larger one, etc. As a result of this “Take Back Effect” the energy savings are less than theoretically possible, even to the level of increasing the energy consumption. A recent study of a “Cash for Coolers” program in Mexico is a pertinent example (Davis, Fuchs & Gertler 2012). In that case a buy-back incentive was provided to customers who turned in an old window air conditioner for a new higher efficiency unit. An extensive energy consumption analysis of all the participants in the program found that the average customer in the window AC buy-back program INCREASED their energy use.

The Mexico experience reminds us that we do not want to increase the size (capacity) of the air conditioners in a household, nor do we want the household to use the air conditioners for longer periods of time. The Kingdom would be well served to carefully structure these changes to avoid these pitfalls.

In order to obtain the change desired, it would be helpful if any incentive be transparent to the customer, meaning that the efficiency of the air conditioner increased, but the customer price did not change. Furthermore it would be desirable that there be a disincentive for customers to “move up” to a higher capacity machine. For these reasons we are suggesting the following:

1. A manufacturer incentive be paid that is approximately equivalent to the manufacturer’s cost increase to comply with the new minimum EERs.
2. The incentives cover the increase in manufacturer’s costs for the 16000h BTU window unit and for the 24000 BTUh mini split.
3. The incentive for window units larger than 16000 BTUh should be the same as for the 16000 BTUh units. This will help avoid an incentive for upsizing the units.
4. The incentive for mini split units larger than 24000 BTUh should be the same as for the 24000 BTUh units. This too will help avoid upsizing units.
5. The incentive for units smaller than the above should be scaled down in proportion the manufacturer’s incremental costs.

### 3-4-10 Introduction of R-410A and R-407C

R-22 will be phased out due to its effect on the ozone layer. It is anticipated that R-410A and R-407C will become the common refrigerants of the future. Both of these refrigerants will require changes in design by the manufacturers if the minimum standards are set and maintained at both T1 and T3. Both of these refrigerants are less effective than R-22 under certain conditions. Emerson (2009) states that the efficiency degradation of R-407C is 7% at 35°C and that the degradation for R-410A at the same temperature is 2%. Work by Domanski and Payne (2002) shows an 11% degradation in R-410A EER at 46°C. The work of El Gallad et al. (2011) showed degradations of over 8% for R-407C at

35°C. Simulations with R-407C showed 6.1% lower condenser capacity at 35°C and 10.6% lower condenser capacity at 46°C (Devotta et al. 2003). Devotta, Padalkar, and Sane (2002) tested the efficiency decrement due to R-407C on a window air conditioner and found the cooling efficiency for R-407C 7.9% lower at35°C and 13.47% at 46°C.The approximate magnitudes of these efficiency decrements compared to R-22 are shown in Figure 73 and Figure 74.

While the exact decrements for typical Saudi air conditioners are unknown, it is evident that the manufacturers will have a challenge to maintain efficiencies as 407C and 410A are introduced.

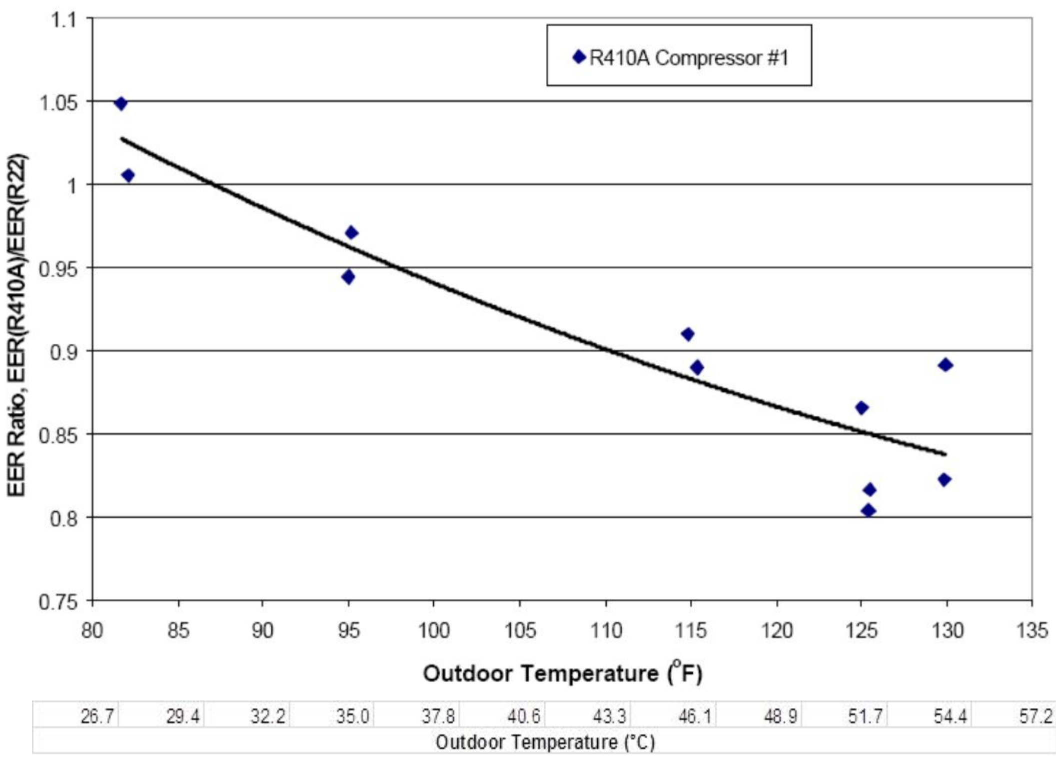


**Figure 73 Efficiency Degradation between R-22 and R-410A vs. Temperature**

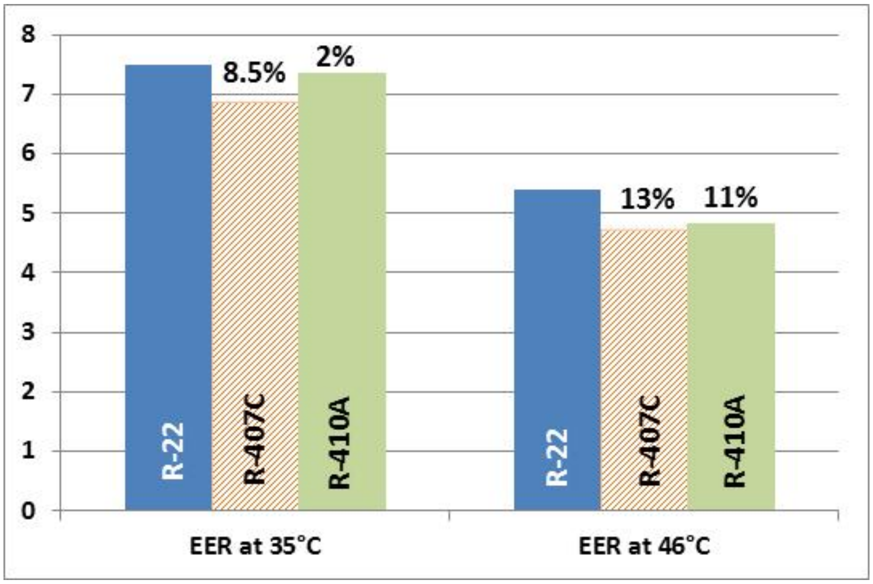


Figure 74 Efficiency Degradation between R-22 and Alternative Refrigerants

Based on the manufacturing challenges associated with changeover from R-22 to R-410A or R-407C, the team suggests that any incentives have a moderate increase if these refrigerants are used in the first few years of the program.

### 3-4-11 Environmental Impacts

The residential customer growth rate is driving up the energy consumption and atmospheric emissions over time. The following table and graph are based on the following assumptions:

1. The annual residential customer growth rate is a compounded 5% per year with the residential customer count 4,675,554 in 2009. The results from an 8% growth rate are shown in Table 1 within the Executive Summary.
2. The $CO_2$emission factor for power generation in Saudi Arabia is757grams per kWh (ABB 2012).
3. The SO2 emissions factor for power generation is 1.235 grams per kWh.
4. The NOx emissions factor for power generation is 0.463 grams per kWh.
5. A 10% replacement rate per year for window air conditioners.
6. A 6.7% replacement rate per year for mini-split air conditioners.
7. The energy savings and environmental emissions reductions are calculated based on an enforced 15% improvement in the minimum window unit EER at T1 and T3 and a 25% enforced improvement in the minimum mini split unit EER at T1 and T3 beginning in Year 1(2014).

   The savings from a 15% increase in efficiency is 0.15/1.15 =13%. Similarly the savings from a 25% increase in efficiency is 20%.

8. The energy savings and environmental emissions reductions are calculated based on an enforced addition of occupancy sensors beginning Year 2(2016). This change is estimated to provide at least a 5% energy savings.
9. The energy savings and environmental emissions reductions are calculated based on adoption of a cycling test for window and mini split air conditioners beginning Year 3(2018). At that time the minimum efficiency of air conditioners labeled for sale in the dry regions of Saudi Arabia will be based on the sensible EER at T3 and will result in at least a 10% energy savings on half the air conditioners put into service from that date.
10. The existing stock of air conditioners will continue to be put into operation for 6 months after the new regulations are in effect and enforced. The existing stock will comprise half the units put into service during that period.
11. Refrigerant R-22 will be replaced by less ozone depleting refrigerants during this period and the manufacturers will have to make efficiency improvements to the units to maintain efficiency at T3.
12. All savings are interacted to account for reduced baseline due to previous savings.

**Table 23 Energy Savings and Pollution Reductions from Proposal by Year**

| Year | # Customers | $CO_2$ Reduction (Annual kton) | | Energy Savings (Annual TWh) | | $SO_2$ Reduction (Annual kton) | | NOx Reduction (Annual kton) | |
|---|---|---|---|---|---|---|---|---|---|
| | | New | Cum. | New | Cum. | New | Cum. | New | Cum. |
| 2014 | 5,967,323 | 500 | 500 | 0.66 | 0.66 | 0.82 | 0.82 | 0.31 | 0.31 |
| 2015 | 6,265,690 | 700 | 1,201 | 0.93 | 1.59 | 1.14 | 1.96 | 0.43 | 0.73 |
| 2016 | 6,578,974 | 899 | 2,100 | 1.19 | 2.77 | 1.47 | 3.43 | 0.55 | 1.28 |
| 2017 | 6,907,923 | 999 | 3,099 | 1.32 | 4.09 | 1.63 | 5.06 | 0.61 | 1.90 |
| 2018 | 7,253,319 | 1,218 | 4,318 | 1.61 | 5.70 | 1.99 | 7.04 | 0.75 | 2.64 |
| 2019 | 7,615,985 | 1,338 | 5,656 | 1.77 | 7.47 | 2.18 | 9.23 | 0.82 | 3.46 |
| 2020 | 7,996,784 | 1,405 | 7,061 | 1.86 | 9.33 | 2.29 | 11.52 | 0.86 | 4.32 |
| 2021 | 8,396,623 | 1,476 | 8,537 | 1.95 | 11.28 | 2.41 | 13.93 | 0.90 | 5.22 |
| 2022 | 8,816,454 | 1,548 | 10,085 | 2.05 | 13.32 | 2.53 | 16.45 | 0.95 | 6.17 |
| 2023 | 9,257,277 | 1,625 | 11,710 | 2.15 | 15.47 | 2.65 | 19.10 | 0.99 | 7.16 |
| 2024 | 9,720,141 | 1,342 | 13,052 | 1.77 | 17.24 | 2.19 | 21.29 | 0.82 | 7.98 |
| 2025 | 10,206,148 | 1,281 | 14,334 | 1.69 | 18.93 | 2.09 | 23.38 | 0.78 | 8.77 |
| 2026 | 10,716,455 | 1,212 | 15,545 | 1.60 | 20.54 | 1.98 | 25.36 | 0.74 | 9.51 |
| 2027 | 11,252,278 | 1,228 | 16,773 | 1.62 | 22.16 | 2.00 | 27.36 | 0.75 | 10.26 |
| 2028 | 11,814,892 | 1,152 | 17,925 | 1.52 | 23.68 | 1.88 | 29.24 | 0.70 | 10.96 |
| 2029 | 12,405,637 | 1,025 | 18,950 | 1.35 | 25.03 | 1.67 | 30.92 | 0.63 | 11.59 |
| 2030 | 13,025,919 | 1,029 | 19,978 | 1.36 | 26.39 | 1.68 | 32.59 | 0.63 | 12.22 |
| 2031 | 13,677,214 | 1,050 | 21,028 | 1.39 | 27.78 | 1.71 | 34.31 | 0.64 | 12.86 |
| 2032 | 14,361,075 | 1,092 | 22,120 | 1.44 | 29.22 | 1.78 | 36.09 | 0.67 | 13.53 |
| 2033 | 15,079,129 | 1,115 | 23,236 | 1.47 | 30.69 | 1.82 | 37.91 | 0.68 | 14.21 |
| 20 Year Total | | | 237,210 (kton) | | 313 (TWh) | | 387 (kton) | | 145 (kton) |

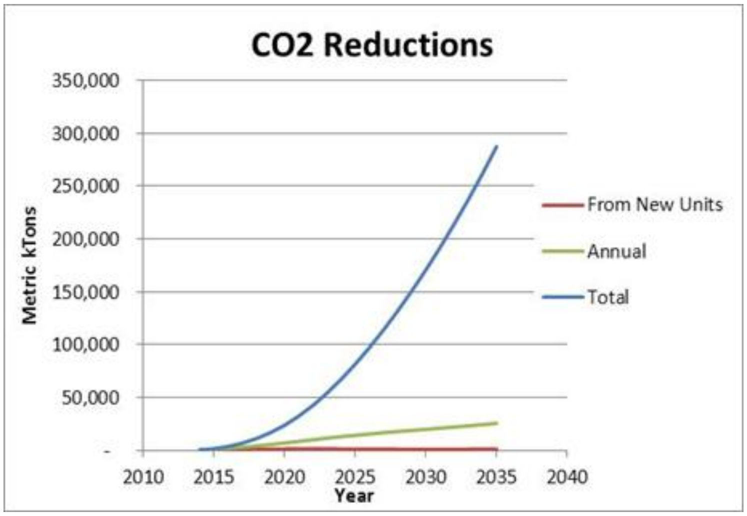


Figure 75 Carbon Dioxide Reductions by Year

# Chapter 4: Conclusions and Recommendations

## *4-1 Conclusions*

1. Saudi Arabia needs air conditioners that do little or no dehumidification for the drier areas and air conditioners that do extensive dehumidification for humid areas. The test procedure should measure the two different types of performance and the minimum standards should be set for each area based on that performance.
2. The potential savings from upgrading window unit efficiency is very large due to the large number of units in the Kingdom, their frequent use, and their low efficiency. The savings are not large enough to attract the consumer to buy a more efficient unit, but the fuel and distribution savings are sufficiently attractive to warrant expenditures to accomplish the changeover and enforcement of a new standard.
3. Window units have significant limitations due to the small size of the cabinet. As the capacity (tonnage) of a window unit increases the possibilities for high efficiency are diminished. Minimum efficiency standards for window units should vary with capacity.
4. Upgrading mini-split efficiency will produce savings sufficient to support expenditures to accomplish the changeover and enforcement of a new standard.
5. Implementing the recommendations in this study is estimated to provide the benefits in Table 24 and Figure 76.

Table 24 Potential Benefits from Implementation

| | Scenario A 5% Compound Growth from 2009 | | Scenario B 8% Compound Growth from 2009 | |
|---|---|---|---|---|
| | Year 1 | Total over 20 Years | Year 1 | Total over 20 Years |
| Fuel Cost Savings (M SAR) | 238 | 112,691 | 328 | 191,773 |
| Generation Cost Savings (M SAR) | 0 | 76,828 | 0 | 92,759 |
| Avoided Electric Consumption (TWh) | 0.66 | 313 | 0.91 | 533 |
| Electric Peak Avoided (MW) | 231 | 11,166 | 319 | 21,689 |
| CO2 Reduction (kton) | 500 | 237,210 | 689 | 403,677 |
| SO2 Reduction (kton) | 0.82 | 387 | 1.12 | 659 |
| NOX Reduction (kton) | 0.31 | 145 | 0.42 | 247 |

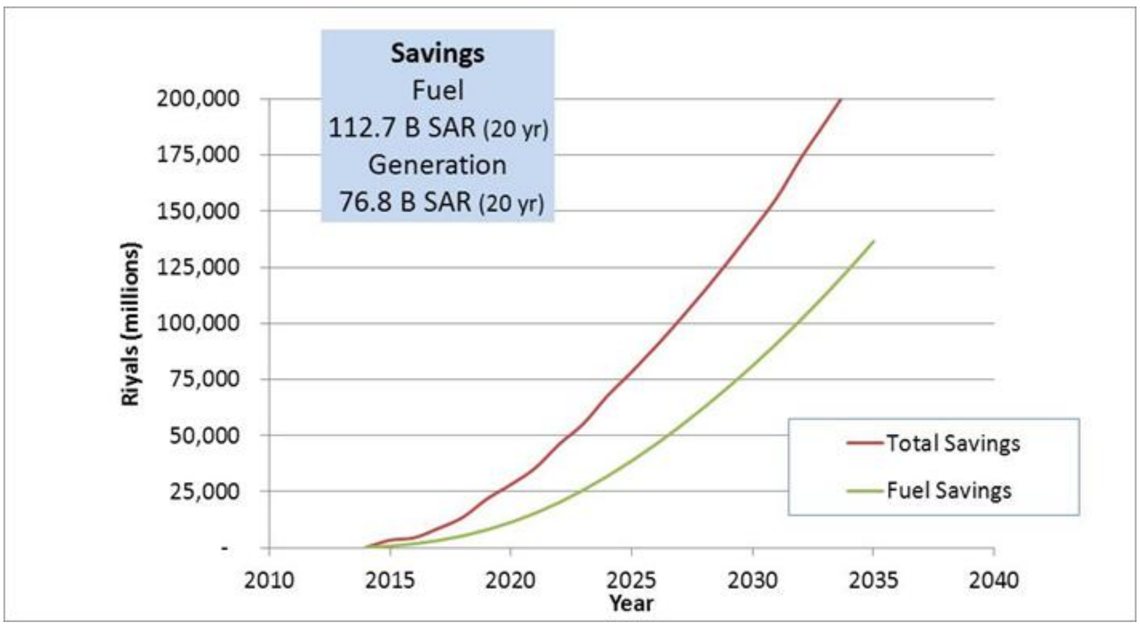


Figure 76 Potential Benefits from Implementation

6. A significant number of units for sale in the Kingdom do not meet SASO acceptance standards for true capacity and efficiency compared to labeled specifications. Enforcement of SASO standards by check testing and deliberate action is needed.
7. The manufacturers will have a challenge to maintain efficiencies as refrigerants 407C and 410A are introduced. Both refrigerants have lower efficiencies than the current R-22 refrigerant. The decrements are probably between 6% and 14% at 46°C.
8. Airflow through the air conditioners is lower than desirable. Low cost/no cost changes can be made to improve airflow and efficiency.

9. To avoid unnecessary air conditioner electrical consumption, the air conditioners should come with occupancy sensors that turn off the unit after the room is unoccupied for some time period.
10. Contrary to some existing literature, analysis of residential billing data indicates that the air conditioning accounts for less than 60% of the residential electrical usage and that it probably averages near 46% of the residential energy consumption. The percentages vary by region with the highest in the Eastern Region and the lowest in the Southern Region. The study estimates that 61% of the residential peak is air conditioning.
11. The current minimum efficiency standards for air conditioners in Saudi Arabia and minimal enforcement are a monetary drain on the Kingdom. Low standards, energy wasting buildings, and low electricity costs combine to make air conditioning very costly to the Kingdom.
12. While the current standard test procedures for window and mini-split units produce EER – a steady state test result, the units should be cycling. To properly assess and capture the potential energy savings in the field, a test procedure that more accurately represents field conditions would be preferable.
13. To be most effective at bringing air conditioning consumption down across the Kingdom will require field monitoring of how the air conditioners operate and their installed efficiencies. These data are likely to point to potential cost effective improvements.
14. Based on the average retail cost for the most common window and mini split units the total costs at the manufacturer are:

- 24000 BTU Mini Splits 1230 SR (328 USD)
- 18000 BTU Window Units 553 SR (147 USD)

### 4-2 Recommendations

1. Provide a two year advance notice in changing the Minimum Standards for Air Conditioner Efficiency.
2. Finalize the method of enforcing the Standard in the first year. In the second year implement enforcement of the existing standard with random check testing and the opportunity for challenge testing.
3. Consider providing a short term incentive to the manufacturer or importer for every air conditioner that is manufactured for and sold in the Kingdom that meets the minimum standards, particularly if it uses R-410A of R-407C as refrigerant.
4. Decertify and remove units from the market that fail check testing or challenge testing in the first and following years.
5. Fine the manufacturer for each decertified unit sold more than thirty days following decertification notification.
6. Focus the Standard on the most important conditions for the energy grid (T3 conditions 46°C outdoors)

7. Provide an incentive within the standard for air conditioners that operate more efficiently under cycling conditions
    a. Provide a standard of test that includes cycling performance of the air conditioner
    b. Provide rating enhancements (points) for specific features that reduce energy use including: occupancy sensors with off time delays, condensate capture and evaporation cooling to the inside unit in dry climates.
8. Provide different standards for varying capacities and types of air conditioners according to the following schedule.

**Table 25 Proposed Standards**

| | Window AC | | Mini-Split |
|---|---|---|---|
| Minimum Standard | < 18,000 BTUh Capacity | 18,000 BTUh or Greater Capacity | All Capacities |
| 2014 (T1 EER) | 9.0 | 8.6 | 9.4 |
| (T3 EER) | 6.7 | 6.4 | 7.0 |
| 2016 Addition | Occupancy Sensor and Time Delay | Occupancy Sensor and Time Delay | Occupancy Sensor and Time Delay |
| 2018 Change | Cycling Test Standard with Sensible EER for Dry Regions | Cycling Test Standard with Sensible EER for Dry Regions | Cycling Test Standard with Sensible EER for Dry Regions |

9. Provide at least two years advanced notice for further increases in the test procedure as well as mandatory minimum Sensible and Total efficiencies

### 4-3 Additional Research

We often consider the most obvious cause of high residential AC electrical use. It is incumbent upon us to point out there are three causes of this high AC use:

1. Building Occupants

    e.g. Some occupants turn the unit to MAX COOL and leave on 24/7

2. Building Thermal Integrity
    a. Air Leakage,
    b. Radiant Gains,
    c. Thermal Insulation
3. The Actual Air Conditioner Efficiency (not-EER)
    a. The test procedure does not represent the actual operation in the homes.
        i. Some AC's Cycle but the test is steady state
        ii. EER is based on Sensible temperature reduction AND dehumidification, but dehumidification is not needed in dry climates
    b. The installation and operating environment reduce efficiency.

i. Mini-split AC refrigerant contaminated with non-condensables
ii. Dust clogs the coils

The above items have 3 to 6 times as much energy savings potential as increased EER

- Occupant Behavior can be modified by mandatory controls specified by the AC Standard
- Test procedure can be modified to test cycling efficiency and specify minimum SENSIBLE EFFICIENCY
- Standard can specify that units must pass a standard dust degradation test

### 4-3-1 Research Recommendations

The team recommends

1. A field study of the actual conditions of the thermal envelope of existing Saudi residences
2. A field study of available retrofits to improve the thermal envelope of existing Saudi residences
3. A field study of the actual operating conditions (indoor temperatures and humidity as well as occupant control, watt draw, and delivered capacity) of window and split air conditioners in existing Saudi residences. This would include electronic monitoring of air conditioners in a wide range of Saudi residences for one year.
4. An air conditioner development program to include alternatives outside the current capabilities of Saudi manufacturers including; heat exchanger types, higher air flow efficiency, higher airflow, condensate capture and reuse for dry climates, fan revisions, and higher efficiency motors.
5. Develop a standard method of test for dust degradation of air conditioner performance.
6. Develop a cycling test for window and Mini-Split air conditioners to be implemented in 2018.

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# Chapter 6: Appendices

## *6-1 Appendix A*
## *Top Down AC Electric Consumption and Peak Load Estimates*

### 6-1-1 Top Down Estimate from Monthly Peak Load

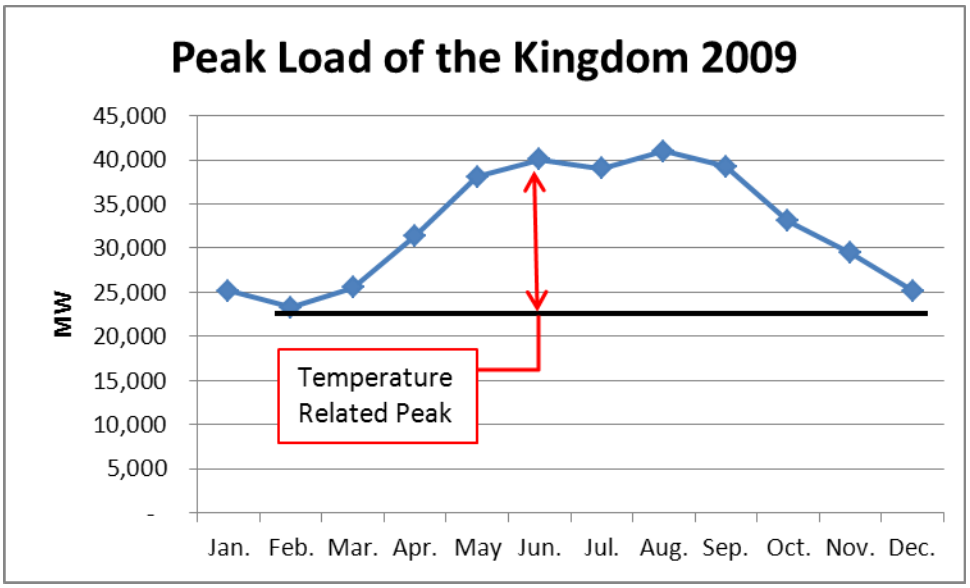


Figure 77 Saudi Peak Load 2009

The difference in peak loads between the month with the highest peak and the lowest peak provides an estimate of the impact of temperature related usage (dominated by air conditioning). The 2009 peak was 41,200 MW and the lowest monthly peak was 23,304 MW in February (MOWE 2009 page 42). This produces a figure of 17,896 MW or 43% of the peak. This estimate is a low side estimate since the peak in February certainly includes some level of air conditioning.

### 6-1-2 Top Down Estimate from Load Duration Curve

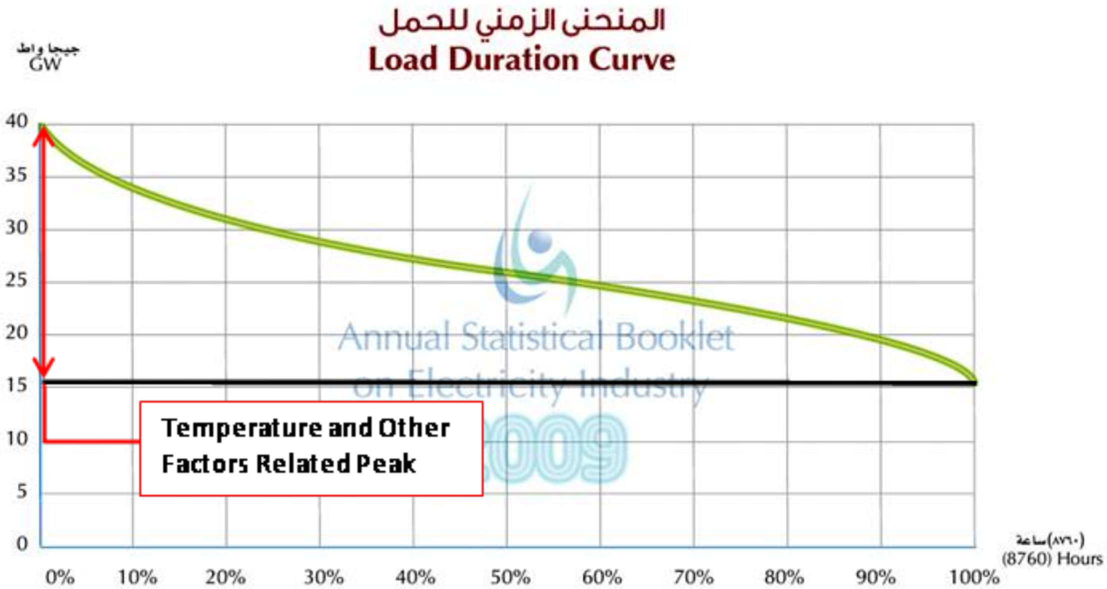


Figure 78 Saudi Electric Load Duration Curve

The difference in peak loads from the load duration curve provides an estimate of the impact of temperature and other variables (time of day, day of week, etc.). If all the difference in electrical load is attributed to air conditioning, the estimate would be 25,000 MW or 61% of the peak.

The load duration curve integrates to about 227,000 GWh[1] of which approximately 96,000 GWh are above 15 GW. The energy consumption above the minimum was approximately 42.3% of the total consumption in 2009.

The percentages of SEC electricity use for the predominant air conditioned sectors are:

- Residences 52.12%
- Commercial Buildings 11.99%
- Government Buildings 13.65%[2]

Residences, commercial and government use 77.76% of the SEC electricity. Assuming residences, commercial, and government are the sectors using the air conditioning and these sectors are using energy for air conditioning in proportion to their overall use, residential air conditioners use 54.4[3]% of their total energy consumption for air conditioning. Using the same assumptions, 16,757 MW[4] of the peak load would be residential air conditioning.

[1] This is higher than the 193,472 GWh total from "Classification and Proportional Distribution of Sold Energy as Consumption". This difference may be due to the difference between source and sold energy.
[2] ECRA sat_book_09.pdf Page 39
[3] 0.423 ÷ 0.7776
[4] 25,000 MW × .5212 ÷ 0.7776

### 6-1-3 Top Down Estimate from Regional Loads vs. Temperatures

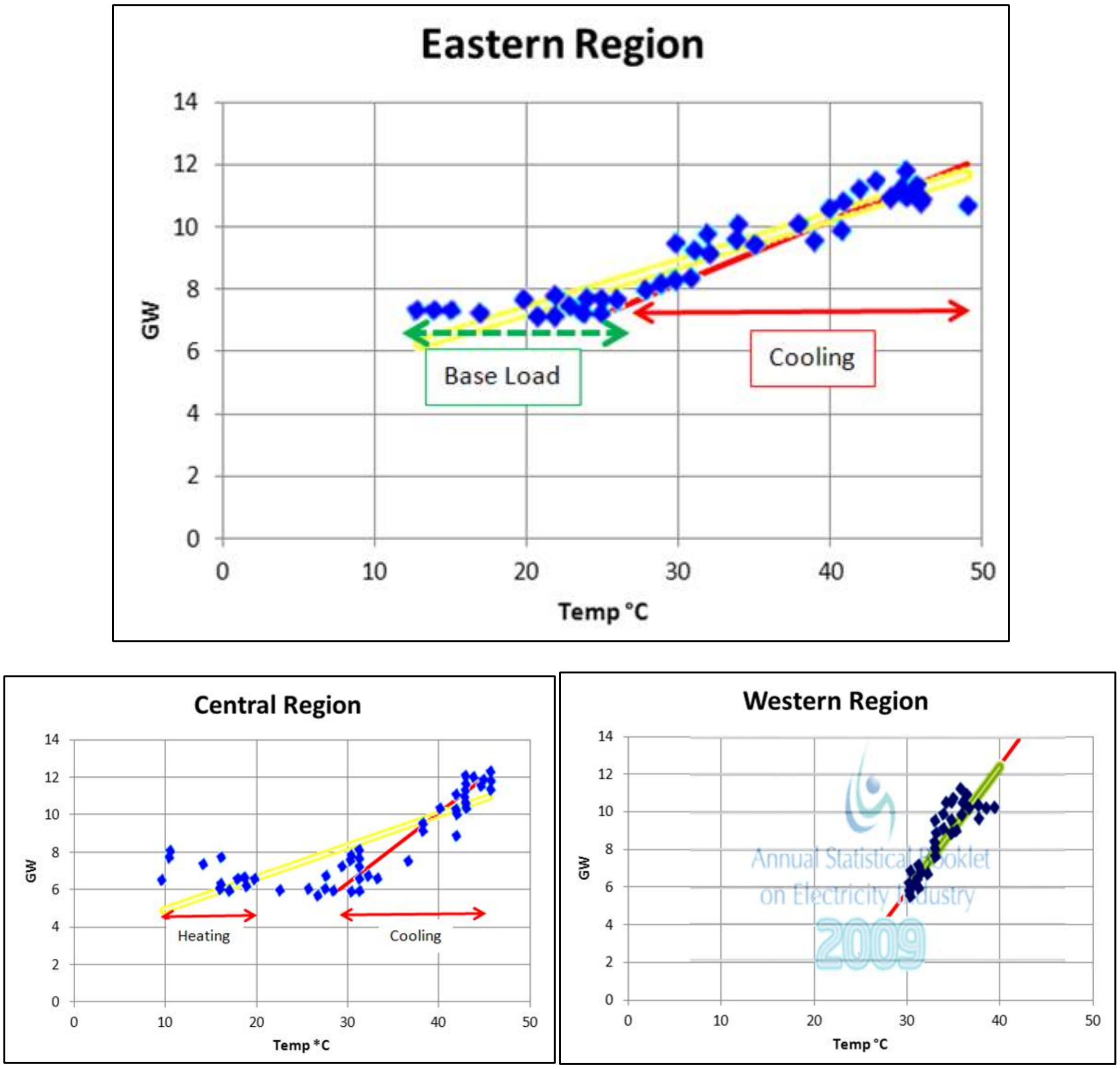


Figure 79 Regional Load vs. Temperature Curves (MOWE 2009)

Regional load vs. temperature curves provide another estimate of the temperature related loads. In the Eastern Region there is a base load of approximately 7,200 MW shown at temperatures below 25°C. That base load is independent of temperature. The vast majority of that load is not air conditioning. In the Central Region the base load is approximately 6,000 MW displayed at temperatures below 29°C and above 19°C. The temperature related use below 19°C is heating related. In the Western Region there is no peak data supplied below 30°C. We are using an estimate of 5,800 MW as the base load for this region.

The apparent rates of increase of peak loads in the regions are:

- Eastern 2,000 MW per °C
- Central 3,759 MW per °C
- Western 6,700 MW per °C
- Southern shows not only the lowest level of energy consumption, but also the least variation in energy generation by week of the year due to the more moderate temperatures in that region.

These statistics produce estimates of temperature related peak of 4.8 GW for the Eastern Region, 6GW for the Central Region, and 5.2 GW for the Western Region. This is a total of 16 GW of temperature related peak load.

### *6-2 Appendix B*
### *Baseline Laboratory Test Records*

This section is omitted from US English Version.