



Variable Refrigerant Flow (VRF) Technology Options DIGITAL SCROLL & INVERTER

Part 1 of 2

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Variable capacity air conditioning systems (also called VRF systems) are gaining in popularity across several markets around the world. Consumers prefer these machines due to the values of energy efficiency, scalability, better comfort etc. The Japanese inverter had been the only incumbent technology to make a VRF system and due to the inherent complexity of the technology, the adoption has not been as fast as expected. The Copeland Digital Scroll is an alternate technology that also provides variable capacity from the compressor but it is delivered more efficiently and in a simpler manner.

This article describes the technical details of the Copeland Digital Scroll and how it functions. In the next part of the article, I am going to provide an in-depth comparison between the Digital Scroll and the DC inverter technology and also talk of the advances being made on the Digital Scroll technology for the future.

Definition of VRF

In traditional a/c systems, there is one indoor unit that is connected with one outdoor unit. This one to one configuration scenario is similar also in the case of chillers or ducted units. In such a/c systems, the compressors are fixed speed devices

and they only operate in two modes – either the compressor is pumping wherein there is full capacity mass flow or the compressor is stopped –

About the Author

Arup Majumdar is director marketing of Emerson Climate Technologies Asia Pacific, based in Hong Kong. Arup has been instrumental in introducing the Digital Scroll technology to multiple OEMs spread across Asia, Middle East, Europe and North America and establishing this technology as a strong alternate to the incumbent Japanese inverter. He has been awarded the Emerson Technology Award for his contribution to establishing this technology globally. Arup is a regular speaker on modulated technologies in various industrial forums globally and has written several technical articles on this topic. He has a B. Tech in mechanical engineering from the Indian Institute of Technology, Kanpur and an MBA from the Indian Institute of Management, Ahmedabad.

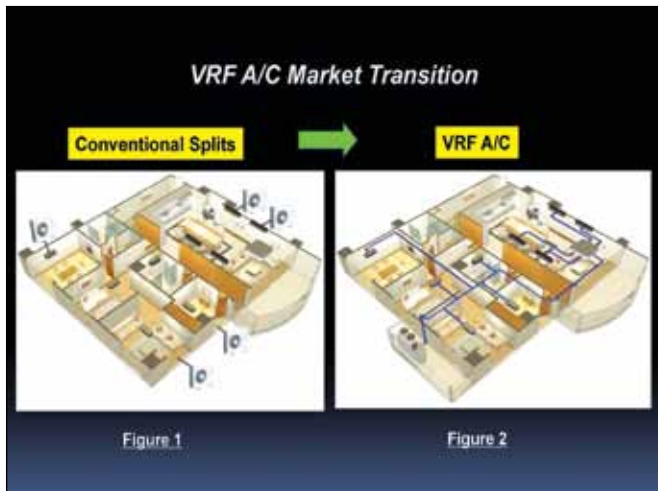


Chart 1: A/C system configurations.

wherein there is no mass flow. Figure 1 in Chart 1, shows such a combination for a residential application— in the air-conditioned space, there are several single split a/c systems and each system is handling a certain area/ room.

There is a growing trend globally towards another configuration (Figure 2 of Chart 1) where all the smaller outdoor units are combined in one large outdoor unit. This product configuration shift, however, needs a technology shift too – the larger outdoor unit has to be a variable capacity box now. In case the air conditioning in one out of the multiple rooms is turned ON, the large outdoor unit should be able to lower its capacity accordingly and deliver only that much capacity as is required to satisfy the room load. If another room/zone is turned ON or if the room load increases, the outdoor machine should be capable to deliver additional cooling capacity. So in essence, the large outdoor box becomes a variable capacity box and delivers variable capacity depending on the room demand. The variable capacity is delivered through variable refrigerant flow from the outdoor unit and is primarily driven by variable capacity from the compressor. Such systems are called as VRF (Variable Refrigerant Flow) systems.

Why Customers Prefer VRF

For fixed capacity traditional systems, the matching of room demand and cooling supply is shown in Chart 2. The X-axis shows the ambient temperature and the Y-axis shows the cooling demand/supply. The white dotted line that is sloping upwards to the right is the room demand. This is intuitive – as the ambient temperature goes up, the room cooling demand also goes up. The blue line sloping down from the left to the right shows the capacity output from a fixed speed compressor/system. As the ambient goes up, the capacity from the machine goes down. As

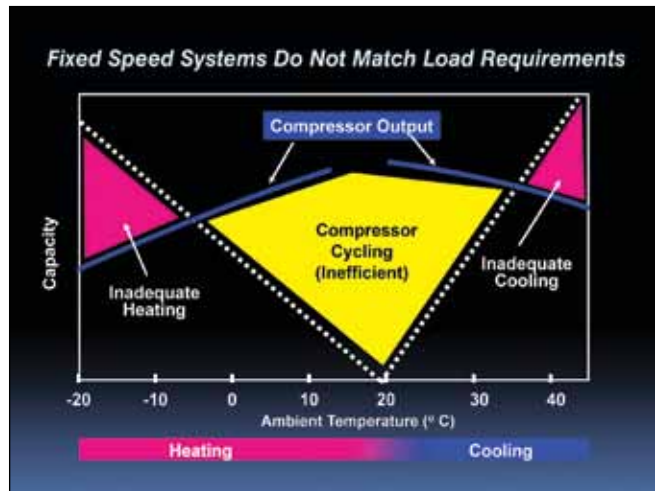


Chart 2: Cooling demand and capacity output from a/c.

can be seen from these two lines, there is only one point at which the demand and supply matches. At all other points, there is a mismatch. If the ambient goes higher, then the red area shows that there is not enough capacity output from the machine and so the room temperature cannot be maintained. If the ambient is low, then there is overcapacity and the compressor continues to switch on and off, and we know that this switching on and off is an energy wasting operation.

This situation changes when we consider the output from a variable capacity machine (VRF). The green line in Chart 3 shows the output from a VRF system and this line follows the demand line very closely. Since the supply and demand of cooling capacity matches, there are several benefits – there is a better room temperature control and this is a more energy efficient operation as the compressor does not do frequent start and stop. At this stage, we would like to introduce you to the two leading technologies for achieving variable capacity – Digital

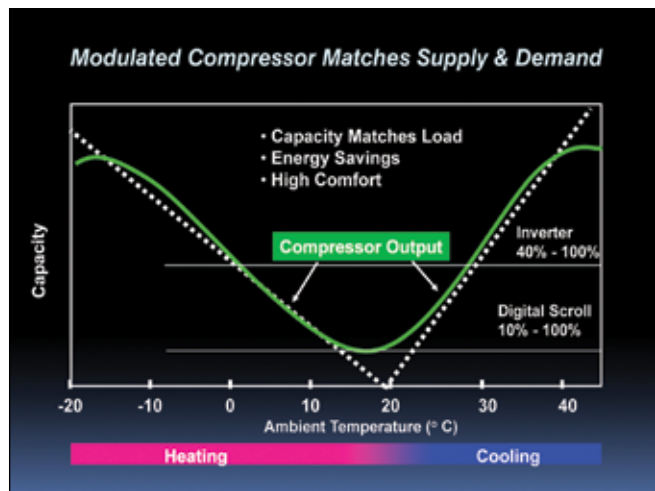


Chart 3: Cooling demand and VRF system output.

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Scroll and Inverter. The Inverter has been the incumbent technology and has been promoted primarily by Japanese manufacturers. The first difference between these two technologies is the range of capacity modulation. As can be seen from the graph, the minimum capacity of the inverter system on a single compressor configuration is 40%, while that for the Digital Scroll is 10%. We will explain the fundamentals of these two technologies so that this difference becomes clearer to understand.

Evolution of VRF Systems in Various Markets Around the World

The Japanese market has been the early adopter of variable capacity a/c systems. In the Japanese residential market (approximately 7 million pieces), which is primarily single split systems, the penetration of capacity modulation is over 98%. In the commercial market, which includes single packaged PAC and also the multi evaporator system, the penetration is over 60% for the VRF technology. Consumers have clearly embraced the values of variable capacity - energy savings and comfort.

Korea is an interesting example. Before the year 2000, Korea had very little capacity modulation in the 3HP and above segments – most of the systems were fixed capacity. Digital Scroll was introduced to the Korean market in 1999, and the first Digital Scroll based system was launched in the year 2000. That provided a huge boost to the VRF market and now, the Korean market has over 50% VRF systems.

China is also an interesting example. In order to provide centralized comfort, three technologies have been used – mini chillers, ducted, VRF, for both the residential and commercial segment. The central market continues to grow strong, but the VRF market is growing much faster as compared to the other segments. We estimate that by the year 2012, the VRF market will be close to a million sets of outdoor units. This represents a substantial market potential and we see several leading Chinese players, like Midea, Gree, Haier, Mitsubishi Haier, York, Mcquay investing and promoting VRF systems.

VRF Technologies - Digital Scroll and Inverters

The inverter has been the incumbent technology for 20 years and so let me start by explaining how inverters work. An inverter uses a variable speed motor on the compressor and an external inverter drive that provides the variable frequency to the compressor motor. When the motor gets the variable frequency signal, it rotates at a speed that is dependent on the Hz. So if a 60Hz signal is given to the compressor motor, the compressor spins at 3,600 rpm. If the frequency goes to 90 Hz, the motor spins at 5,400 Hz. Depending on the manufacturer, the range of

frequency delivered by the inverter driver can vary from 28 Hz to 110 Hz. It should be noted that there are several limitations on operation at various frequency ranges – for example, the compressor cannot run continuously at high speed for an extended duration.

One of the reasons why VRF systems using the inverter technology have not been very popular outside Japan, given all the advantages that it offers to the end user, is the complexity of the technology. Here are some of the design challenges faced by engineers when designing and applying the inverter systems:

- Resonant frequency : The inverter compressor operates at variable speed and so adequate attention has to be paid to make sure that there is no resonance in the various pipes and sheet metal in the system. In case this is not done properly, sound can propagate through the tubes and permeate to the indoor side into the room and can also cause failure of copper tubes.

- There is a limitation on the lowest speed of the inverter due to bearing lubrication consideration and so typically, the lowest capacity is around 40% for single compressor system. This means that when the room demand is less than 40%, the excess capacity has to be bypassed. There are several bypass circuits and solenoid valves in the inverter system that perform this function. Adding bypass circuits make the system less efficient and also complicate the mechanical architecture - affecting the reliability of the system.

- The inverter controller is expensive. There is a significant amount of electronics hardware in the inverter controller and that adds to the cost and complexity of the system.

- One of the major reason that inverter systems fail is oil return. Typically at 50Hz, the oil circulation rate is around 1-2% in a scroll compressor. The oil circulation rate is the amount of oil that leaves the compressor as a percentage of the refrigerant being pumped. It is measured as = (weight of oil leaving the compressor during pumping/ weight of refrigerant being pumped). When the frequency and speed of the inverter compressor increases, the oil circulation rate also goes up. It can go up as much as 8% which means that if the discharge gas is trapped and weighed, 8% of the weight will be oil (this means that a lot of oil leaves the compressor during high speed operation). With long pipe lengths, there is a significant chance that the compressor can lose a large amount of oil and if this oil is not returned in time to the outdoor unit, the compressor can fail due to lack of lubrication. Special care has to be taken in an inverter system to ensure adequate oil return to the compressor.

- The inverter electronics emit a significant amount of

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electromagnetic interference that can cause disturbances to other electronic equipments. This is particularly acute for telecommunication, hospital, computer rooms etc applications. To suppress this emission, inverter manufacturers use suppression equipments which add cost and also complexity to the system.

- The inverter equipments are complicated and servicing is not easy. In developing markets, where shortage of skilled technicians is a challenge, this can be a major bottleneck.

- Whenever the power passes through the inverter electronics, there is an inverter loss. Whether it is an AC inverter or a DC inverter, there are losses and the losses can range from 7% (for a good inverter) to 15% for the average inverter.

Copeland Scroll Technology

We will briefly explain how the standard Copeland Scroll works as it will help in the understanding of the Digital Scroll. Inside the compressor, there are two components that are called the scroll sets. *Chart 4* shows how they look physically.

The two scrolls mesh against each other in the compressor. *Chart 5* shows the cross section taken when the scrolls are meshing against each other – the dark line is the profile of the fixed scroll and the gray line is the profile of the orbiting scroll. There are several pockets that are formed when the scrolls mesh with each other. The pocket of compression on the outside (which is the longest and traps the most refrigerant) moves inwards as the scrolls orbit. As the pocket of gas moves progressively towards the center, it gets smaller in size and gets compressed more and more. Finally, at the center, where the size of the pocket is the smallest, the gas is discharged at a high pressure.

There is a unique feature in the Copeland Scroll



Chart 4: Scroll sets.



Chart 5: Pockets of compression inside the scrolls.

called “axial compliance” that is the basis of the Digital Scroll. When the two scrolls are meshed with each other, they have to be held in the axial direction with a right amount of force. If the scrolls are held too tightly together, then the frictional losses during the scroll orbiting will be high. The EER/COP is defined as cooling capacity delivered divided by power consumption. If the frictional force goes up and consequently the power consumption, the EER of the compressor will reduce. But if the scrolls are held together lightly, then there will be leakage of refrigerant from the high pressure side to the low pressure side through the scroll tips. If that happens, there will be capacity losses and consequently the EER will drop. This means that there should be an optimal force that has to be used to hold the two scrolls together to ensure the highest EER from the compressor. This force is however, not a constant force and depends on the ambient temperature. If the ambient is hot, the pressures inside the a/c system are

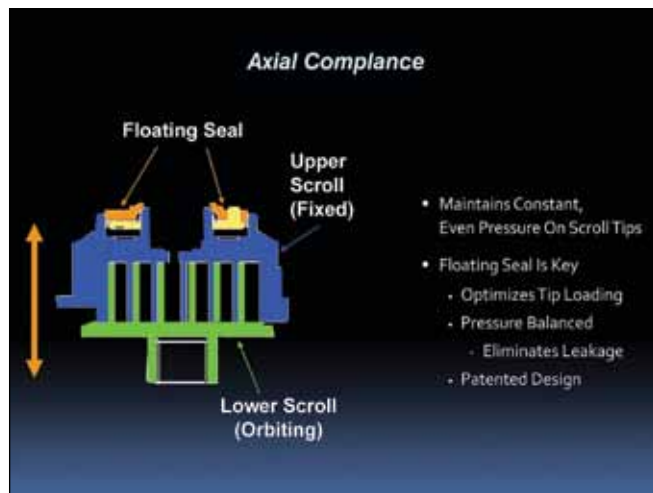


Chart 6 : Holding the two scrolls with optimal force.

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higher and so the holding force has to be higher. If the ambient is lower, the system pressures are lower and so the holding pressures have to be lower. The Copeland Scroll employs an unique patented component called the floating seal, that is shown in *Chart 6* that ensures that the two scrolls are always held together with the right amount of force. That is the physics behind the superior EER performance of the Copeland Scroll.

Digital Scroll Technology

The beauty of Digital Scroll technology is its inherent simplicity. As explained before, the standard Copeland Scroll has a unique feature called “axial compliance”. This feature allows the fixed scroll to move in the axial direction, by very small amounts, to ensure that the fixed and orbiting scrolls are always loaded together with the optimal force. This optimal force holding the two scrolls together at all operating conditions ensures the high efficiency of Copeland Scrolls. The Digital Scroll operation builds on this principle.

The two scrolls are shown in *Chart 7*. During the normal compression process, the two scrolls are always held together with the optimal force in the vertical direction. However, through some mechanism, if the fixed scroll is made “unfixed” and is lifted by only 1 mm, there would be no gas compression even though the motor and the orbiting scrolls are moving. This is the simple mechanism of the Digital Scroll. The fixed scroll on the top is moved up by one mm (in order to get no compression) and pushed down and meshed with the orbiting scroll (in order to get compression). The up and down movement of the fixed scroll is achieved through a pressure differential/spring arrangement inside the compressor and is actuated by an external solenoid valve. A 220V supply to the external solenoid valve makes the fixed scroll go up by one mm and 0V to the solenoid engages the two scrolls back again.

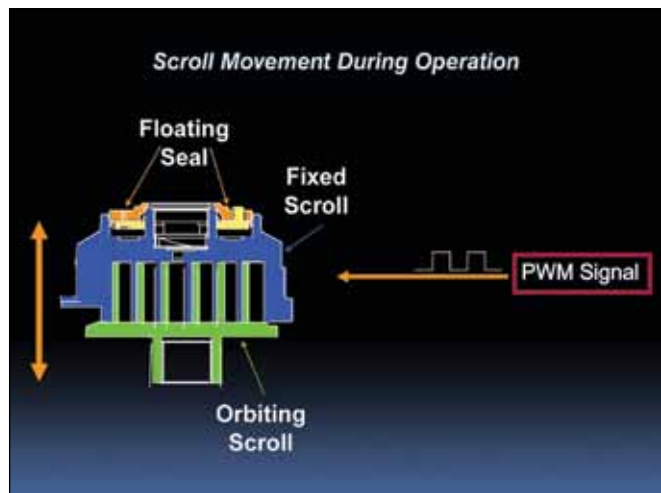


Chart 7: Fixed scroll moves up and down by 1.0 mm.

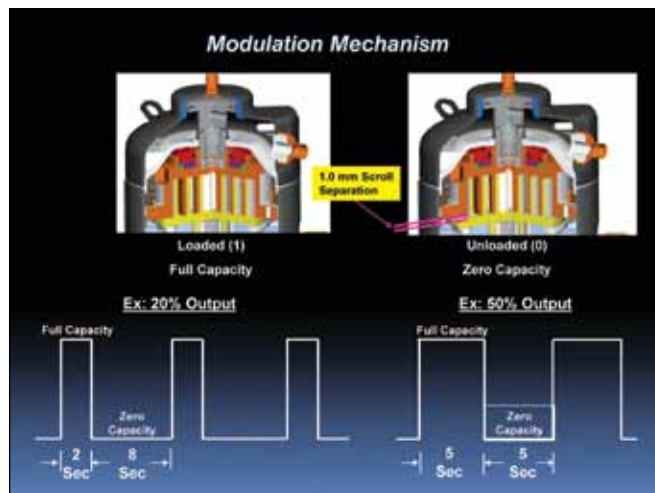


Chart 8: Loading and unloading of the Digital Scroll.

The Digital Scroll operates in two stages – the “loaded state”, when the solenoid valve is normally closed (0V to solenoid coil) and “unloaded state”, when the solenoid valve is open (220V to solenoid coil). During the loaded state the compressor operates like a standard scroll and delivers full capacity and mass flow. However, during the unloaded state, there is no capacity and no mass flow through the compressor and during the unloaded stage the compressor consumes only 10% of the full load power. The two states of the Digital Scroll are shown in *Chart 8*.

At this stage, let us introduce the concept of a cycle time. A cycle time consists of a “Loaded State” time and “Unloaded State” time. The duration of these two-time segments determine the capacity modulation of the compressor. Example: In a 10 seconds cycle time, if the loaded state time is 2 seconds and the unloaded state time is 8 seconds, the compressor modulation is (2 seconds × 100% + 8 seconds × 0%) / 10 = 20% (*Figure 2* in *Chart 8*). If for the same cycle time, the loaded state time is 5.0 seconds and the unloaded

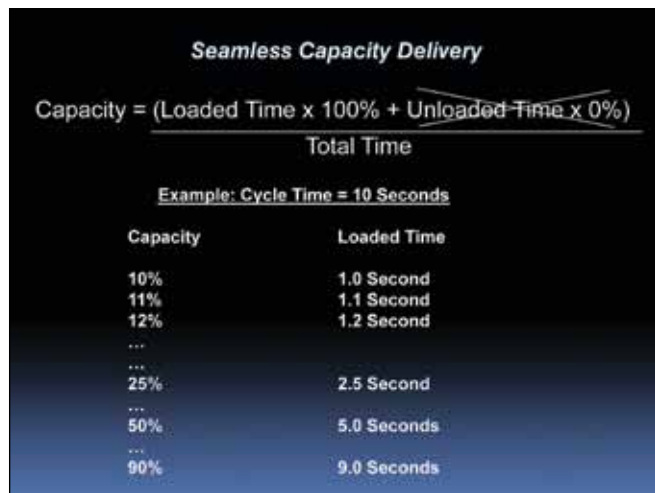


Chart 9: Seamless capacity delivery.

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state time is 5.0 seconds, the compressor modulation is 50%. The capacity is a time averaged summation of the loaded state and unloaded state. By varying the loaded state time and unloaded state time, any capacity (10%-100%) can be delivered by the compressor.

Chart 9 shows the simple formula that can be used to calculate the capacity output from the compressor by varying the loaded and unloaded time. As can be seen from the formula, this technology provides a seamless capacity output from 10% to 100%.

Benefits of VRF System with Digital Scroll

Digital Scroll technology offers several benefits and some of them are listed below:

- **Wide capacity range from 10% to 100%:** Capacity from 10%-100% is an unmatched output from the Digital Scroll. This wide capacity output is continuous and seamless. This is an enhancement over the inverter technology, where capacity outputs can only be achieved in steps. The seamless delivery of capacity also ensures that there is a very tight control on room air temperature. A wide capacity output also contributes to a high seasonal energy efficiency of the system. Start – stops of the compressor consumes more energy. The wider capacity output of the Digital Scroll reduces the number of start- stops.

- **High seasonal energy efficiency:** For modulated systems, single point efficiency is not the right measure of the efficiency of the system. The Integrated Part Load Value (IPLV) has to be calculated to get a good idea of the savings from operating the system year- round. The Digital Scroll performance has been evaluated as per the ARI standard and it shows excellent IPLV. The IPLV advantage becomes even greater for a tandem configuration – a Digital Scroll compressor in tandem with a fixed speed compressor. At full load capacity, when both compressors are operating, the system has a high EER and at 50% capacity, when only one compressor is operating at full load, the system operates at high EER also.

- **Easy oil return that translates to superior reliability:** Oil return is a major issue in variable capacity multiple evaporator systems. Inverter technology uses an oil separator and/or complicated oil return cycle to ensure oil return after some period of operation. The Digital Scroll is a unique compressor – it does not require an oil separator or an oil return cycle. There are two factors that make the oil return easy. Firstly, the oil leaves the compressor only during the loaded cycle. So at low capacities, very little oil leaves the compressor. Secondly, as explained before, the compressor operates at full capacity during the loaded cycle. The gas velocity in the loaded cycle is sufficient to return oil back to the compressor.

- **Better dehumidification at part load operation:**

Dehumidification is necessary to ensure customer comfort and this becomes more important during low modulation operation (example: rainy season). In the inverter system, at low modulation, the compressor operates at a lower frequency. This reduces the mass flow of refrigerant and results in a higher suction pressure. This results in a higher Sensible Heat Factor (SHF). The Digital Scroll compressor provides very good dehumidification because it operates at a lower suction pressure than the inverter. As mentioned before, during any modulation output, the compressor operates at full capacity during the loaded part of the cycle. This full capacity operation results in a lower average suction pressure that leads to a lower SHF.

- **Zero emission of electromagnetic interference:** Electromagnetic interference is a major issue in inverter driven systems. In many countries, particularly Europe, there are strict regulations on the amount of electromagnetic interference that any device can emit. The Digital Scroll system generates negligible electromagnetic interference as the loading and unloading of the scrolls is a mechanical operation. This unique feature not only eliminates the need for expensive electromagnetic suppression electronics, it also adds to the reliability and simplicity of a Digital system.

- **Rapid temperature pull down in the room and room temperature control of 0.5°C:** Quick pull down of room temperature and quick adjustment to demands are essential for customer comfort. Digital Scroll, because it can transition from 100% capacity to 10% capacity or vice versa instantaneously by changing the loaded and unloaded cycle time, can react to the changes in system demand faster without having to pass through intermediate speed changes as is necessary in the inverter systems.

- **Reliability of system and electronics is an issue in developing markets in Asia.** In an inverter system, the electronics is typically complicated and exposing this complicated electronics to the uncertainties in installation and the extremes of weather, results in a reliability issue. The situation is made further complex by the usage of various bypasses – hot gas bypass and liquid bypass. The Digital Scroll technology has a proven field reliability of 99.997%

Summary

Digital Scroll is a variable capacity compressor that enables the design of a very energy efficient and reliable VRF system. The technology is fundamentally simple and also unique and addresses all the problems that have been associated with the old inverter technology. OEMs globally are adopting this technology and end users are able to achieve a superior level of comfort while saving on their energy bills. ❖