Studies on the Characterization of Glazing and Fenestration for Energy Efficient Building System

A thesis submitted towards partial fulfillment of the requirements for the degree of

Master of Technology in Energy Science and Technology

Submitted by

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **"Studies on the Characterization of Glazing and Fenestration for Energy Efficient Building System"** is a bonafide work carried out by **RUPESH KUMAR** under our supervision and guidance for partial fulfillment of the requirement of Master of Technology in Energy Science and Technology in School of Energy Studies during the academic session 2017-2019.

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Committee of final examination for evaluation of Thesis

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I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of his **Master of Technology** (Energy Science and Technology) studies during session 2017-2019.

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NOMENCLATURE

A	Area (m^2)
C	Specific heat of glazing (kJ/(kg K))
D_λ	Relative spectral distribution of illuminant D65
D65	Standard illuminant
k	thermal conductivity of glazing material (W/(m K))
Q	rate of heat flow (W/m^2)
Δt	change in temperature
$V(\lambda)$	Spectral luminous efficiency for photopic vision defining the standard observer photometry
$\tau(\lambda)$	Spectral transmittance of the glazing
$p(\lambda)$	Spectral reflectance of the glazing
ε	Emissivity of glazing surface
λ	wavelength
τ_v	light transmittance of the glazing
p_v	light reflectance of the glazing
$\Delta\lambda$	Wavelength interval (nm)

Table of Contents

Chapter 1: Introduction

1.1 General Introduction

The energy consumption of the world is rapidly growing day by day as a result of the remarkable increasing trend of world population, growing demand for transportation and building services, and rising comfort levels with technology, leading to serious environmental impacts such as ozone layer depletion, global warming and climate change. Thus there is a global consent among scientists that the existing energy resources will be exhausted in the near future. This issue has prompt developed and developing countries to recheck their energy policies regarding energy production and consumption. Recent reports indicate that the renewable energy sources currently can meet only 14% of the global energy demand [1], which is not sufficient for a decisive measure. Therefore, energy minimization and its efficient use are globally required.

The commercial and residential buildings play a major role in energy consumption. Energy in various forms is used in buildings for providing various basic needs. However the nature of energy demand depends on local climatic condition. The countries near the tropic of cancer and Tropic of Capricorn experiences the maximum possible incoming solar flux. This leads to the rise in ambient temperature inside the building. The building situated in this zone thus receives large amount of solar radiation, which subsequently gets converted into heat. This heat ultimately flows inside the building and increase the inside temperature of the building. This intern changes the comfort temperature for the incumbents and the space demands suitable cooling and thus requires more energy.

In buildings windows play an important role in energy performance as it provides air ventilation, passive solar gain, day lighting. It is a fact that solar radiation which is directly incident on a glass surface is transmitted within the building to the extent of 88% [2]. Moreover glazing materials in windows provide sufficient illumination levels in the interior of buildings receiving the visible part of solar radiation and also protects from harmful ultraviolet rays which passes through the earth's atmosphere. The other part of solar radiation in the infrared region entering through glazing causes increase of interior temperature. In this era modern buildings are often characterized by large windows of glazing materials. With the increased usage of glazed areas the heat gain in the buildings also increases leading to larger cooling load. Hence glazing is a major component in analyzing problems such as energy demands, evaluation of heating and cooling loads and thermal comfort in a building. Not only the type of fenestration but building orientation also plays an important factor for heat gain/loss in building envelope. Again the heat gain depends upon how much total solar radiation irradiated on various surface of building depending on building orientation [3, 4]. Therefore, proper selection of glazing material can reduce the solar heat gain component thus reducing cooling loads in summer as also reduce heat loss in winter.

1.2 Review of earlier work

Cristian Cueavas et al. [5] experimentally studied to determine correlations that allowed the calculation of heat transferred by convection through the window. Three configurations were studied: a hot plate; a cold plate and a window with a single-step frame placed on the wall of a room. They obtained a correlation that can be used to calculate the convection heat transfer through the window and the models were valid for natural convection and for Grashoff numbers between 3×10^8 and 2×10^9. M.K.Urbikain et al. [6] aimed to obtain a Window Energy Rating System (WERS) for two climatic zones in Spain. The first part of this research consisted of comparing different methods to obtain energy gain or losses due to windows by applying them to a building for different climatic zones. The second was to propose a Window Energy Rating System (WERS) that would be indicative of window performance for residential buildings in the Basque Country. M.C. Singh et al. [7] investigated on the energy rating of different window glazings, available in the Indian market. This rating was helpful in selecting the best window for a given building and a given climate. It was shown that savings by a window w.r.t. the base window (single glazed, clear glass, 6 mm thick), depended upon window type, its orientation, climatic conditions of the place, buildings dimensions and thermal transmittance of its walls and roof. Aritra Ghosh et al. [8] described variation of the vacuum glazing transmittance with clearness index because glazing transmittance variation with clearness index has higher influence than incident angle for solar energy application. The reduction of building energy consumption can be possible by using advanced adaptive glazing technologies. Yueping Fang et al. [9] described the thermal performance of an electrochromic vacuum glazing and a vacuum glazing with a range of low-emittance coatings and frame rebate depths were simulated for insolations between 0 and 1000Wm^{-2} using a three-dimensional finite volume model and compared in detail.

Another work was presented by T. R. Nielsen et al. [10] comparing the energy performance of different glazings or windows in an easy way. In this paper results were shown on the basis of simple method because it required only few calculations and it was compared with detail building simulation programme where it require a large amount of input. Jianfeng Zhang et al.[11] investigated on the side edge sealing of vacuum glazing using laser soldering method under a relative vacuum environment, prepared the solders by the excellent performance of $PbO\text{-}TiO_2\text{-}SiO_2\text{-}R_xO_y$ system sealing solder to seal the vacuum glass, the microstructure and energy spectrum analysis of the sealing layer had been conducted. Aritra Ghosh et al. [12] analyzed on correlation between clearness index and glazing transmittance, transmitted solar energy and solar heat gain coefficients for SPD glazing in its “transparent” and “opaque” state. Roberto Zanetti Freire et al. [13] aimed to analyze the modeling level that was needed to successfully evaluate the heat transfer through glazing parts of windows in whole-building energy simulations. In this way, predictions of glazing surface and zone air temperatures and energy demand were obtained using both resistive and finite-volume based models and also were compared. Junyan Zhao et al. [14] have described a method to produce transparent spacers, which allows for the production of novel nearly transparent vacuum glazing. Yueping Fang et al. [15] researched on the thermal performance of the triple vacuum glazing (TVG) which was simulated using a finite volume model. Using this finite volume model, this paper investigated the effects of the following variables on the thermal performance of TVG: (i) solder glass and indium edge seals; (ii) edge seal width; (iii) size of TVG; and (iv) frame rebate depth. The numerical simulation results were compared with those calculated using the analytic model. C. F. Wilson et al. [16] researched over the heat flow in vacuum glazing through the support pillars placed in the narrow internal evacuated gaps in vacuum glazing. The aim of the paper was to develop methods for calculating the magnitude of this heat flow, and the associated temperature non-uniformities on the external surfaces of the glazing, which do not require complex numerical procedures and large computational resources.

The optical properties of window glazing was measured by Sujoy Pal et al. [17]inorder to determine the percentage absorption of incident solar radiation inorder to account thermal comfort and overall energy consumption of a building. An experimental study was performed in a room to measure the glazing surface temperature due to the global radiation on it. Mathematical models were developed to simulate the window plane solar radiation and corresponding glazing surface temperature aiming at validating the measured values. Yueping Fang et al. [18] investigated on the thermal performances of vacuum glazings employing coatings with emittance between 0.02 and 0.16 which were simulated using a three dimensional finite volume model. Aritra Ghosh et al. [19] described outdoor test cell which offered to measure the overall heat transfer coefficient, and solar heat gain coefficients of a vacuum glazing under an uncontrolled dynamic condition. Internal illuminance of this vacuum glazing was measured and compared with double-glazing. Erdem Cuce et al. [20] presented a novel vacuum tube window technology where its thermal performance efficiency was both experimentally and numerically investigated. The thermal insulation performance of vacuum tube window technology is experimentally analyzed in an environmental chamber and for numerical analysis a CFD based research was conducted.   Amrita Ghosh et al. [21] compared the effect of geometrical factors like window to wall ratio (WWR) and window positioning on the heating, cooling and lighting energy consumption of a South facing building cell in warm and humid climate. The study also proposed the design of an external shading device which, when compared with the existing shading designs, leads to reduction in annual energy consumption of the building.

Tin-tai Chow et al. [22] gives a brief overview of the developed as well as emerging advanced window technology for cooling-demand climates. Their energy performance has been discussed and illustrated through the use of specific sunny summer conditions. Then the innovative concept of water-flow window is introduced and the potential areas of application were discussed. Jun Fu Zhao et al. [23] described a modified pump-out technique, incorporating a novel pump-out hole sealing process that enables a high level of vacuum to be achieved between the panes of a vacuum glazing. Aritra Ghosh et al. [24] investigated on the suspended particle device (SPD) glazing inorder to measure the overall heat transfer coefficient. The experimental data of the SPD glazing was compared with the experimental data of a sample of a double glazing unit with a similar area and the behavior of SPD glazing sandwiched with double glazing was also investigated. N. Ng et al. [25] described methods for characterizing the thermal insulating properties of vacuum glazing-two flat sheets of glass, hermetically sealed together around the edges containing a highly evacuated space, and separated by small pillars and methods described were guarded hot plate, transient technique, cool-down method. H Manz et al. [26] investigated on the achievable thermal transmittance of triple vacuum glazing based to a large extent on the concepts and technologies developed by other authors for double vacuum glazing. This study investigated on the theoretical potential of glazing with two evacuated cavities and support pillar arrays. Nijnatten [27] measured the directional reflectance and transmittance of coated and uncoated glazing samples by setting new accessories in a spectrophotometer.

1.3 Objective and scope of the work

The primary objective of this thesis is to evaluate and compare the optical properties of various glazing materials. In the first part data for spectral transmittance and spectral reflectance were taken in UV, visible wavelength region using a Perkin-Elmer lamda-35 spectrophotometer. This data were stored using lamda-35 software which was installed in computer interfaced with spectrophotometer. Thus the solar optical properties are determined from these spectral data using British Standard (BS EN 410) [28] method and comparison of spectral transmittance and spectral reflectance are done at various angle of incidence of light. In the second part spectral transmittance and spectral reflectance data were taken for UV, visible and infrared wavelength using Jasco V-770 spectrophotometer and the transmittance and reflectance characteristics is compared with the characteristics measured by Perkin-Elmer lamda-35 spectrophotometer. Here our primary purpose is to study the optical characteristics of spectral transmittance and reflectance at various angle of incidence of light for different samples and compare this with spectral data found using Jasco V-770.

Our study focuses on measuring the optical properties like spectral transmittance and reflectance from which we can determine the percentage solar absorption of incident solar radiation which will be helpful in evaluating the thermal performance within building interiors to account thermal comfort and overall energy consumption of a building since the effect of solar radiation on windows and glazing system for the evaluation of heat flow is one of the important aspect for energy efficient buildings. Modern buildings are more focused to improve the daylight availability in the interiors, offer better external views and also add to the architectural beauty of the building but due to the increased glazed area it has also allowed substantial solar energy to enter and heat up the building. This is especially critical in hot and humid tropical regions, where reducing solar heat gain, while minimizing heat loss are equally important and this could be done by evaluating the optical and thermal properties of various glazed system like single glazed system, double glazed system etc and thus it will help in evaluating energy consumption on the heating, cooling and lighting of a building regarding various climates and also based on the orientation of the windows in the building.

Chapter 2: Advanced Glazing System

2. 1 Introduction

Windows are complex and interesting elements in the fabric of a home. They let in light and fresh air and offer views that connect interior living spaces with the outdoors. However, windows can be a major source of unwanted heat gain in summer and significant heat loss in winter. Thus from thermal insulation point of view, window is most vulnerable. So glazing plays an important role in this aspect. Therefore, Energy efficient glazing system are required to make our home more comfortable and at the same time dramatically reduce our energy costs and help us to create a brighter, cleaner and healthier environment.

Solar spectrum ranges from ultraviolet to radio wave but due to the air mass at earth surface being 2.5 the solar radiation on earth surface ranges from wavelength of 300-2500 nm [29]. Thus solar spectrum on earth surface is divided into three bands which are:

- Ultra-violet light (UV) – 300nm-380nm
- Visible light – 380nm-780nm
- Infra-red light – 780nm-2500nm

The energy distribution within the solar spectrum is approximately 2% UV, 47% visible and 51% infra-red. Only the visible light band is seen by the human eye. Solar irradiance incident on a glass is partly reflected, partly transmitted through the glass and the remaining is absorbed by the glass material. Thus it was always a try to make window insulation prominent.

As a result, glazing systems have been modified from single glaze to double glaze and recently developed multilayer evacuated glazing. Heat losses (U) through single glazed units were significantly high (U-value of 5.3 W $m^{-2}K^{-1}$) [30]. To acknowledge this heat loss, double glazed units were manufactured. Initially, double glazed units were air filled. But due to conductive nature of stagnant air, significant heat loss was observed. Gradually noble gas filled double glazing units have been developed. With this modification, conductive heat loss was reduced, but not eliminated; as any noble gas possesses very small conductivity (0.016 W $m^{-1}K^{-1}$for argon) [31]. With this modification, conductive heat loss was reduced, but not eliminated; as any noble gas possesses very small conductivity (0.016 W $m^{-1}K^{-1}$for argon)[32]. Later, evacuated glazing units were fabricated. Evacuated gazing units are similar to double glazing units where the internal air space between two glass panes is evacuated to very low pressure (less than 0.1Pa) [33]. With evacuated glazing units, conductive and convective heat flow was reduced to a negligible value. But problem with such systems was radiative heat transfer which was reduced by applying low emittance coatings. Transparent insulating material (TIM) based glazing systems also showed improved thermal performance [34, 35]. TIM based glazing unit is also similar to double pane glazing units where the internal space between two glass panes is generally filled up by aerogel. Attachment of an electrochromic layer with evacuated glazing units added an extra advantage of controlling solar gain.

Moreover the impact of glazing on the thermal performance of a building is complex like we have to consider many factors like:

- climatic conditions in your location — temperature, humidity, sunshine and wind
- building design — the orientation, form and layout of the building
- building materials — the amount of mass and insulation
- the size and location of windows and shading
- thermal properties of glazing systems.

2.2 Single Glazed System

In most simple terms, single glazed system consists of a single pane of glass which separates the outside environment with the inside of the building which we can see in Fig 2.1 and from Fig 2.2 shows the energy flow paths at a single-pane window glass when solar radiation is incident on it. Solar irradiance G (including the direct component from the Sun and the diffuse component from the sky, clouds, and surrounding objects) incident on the window glass is partly transmitted and partly reflected. The remaining portion is absorbed within the glass material that may include the coatings and/or ingredients if there are any. At the center of glass, the absorbed portion will be transmitted inward, as well as outward, by the processes of conduction, convection and long wave radiation [36].

Fig: 2.1 Single Glazed Window

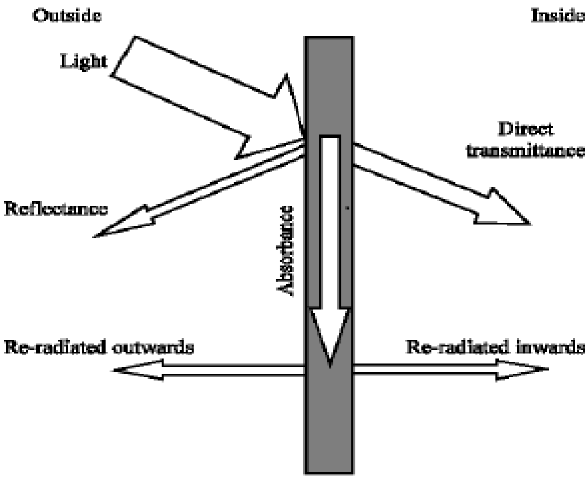


Fig 2.2 Energy flow paths at single-pane glazing

Some of the benefits of single glazing include:

- Do not always require newer frames. Due to the fact that only a single glass pane is present in single glazing, they can be installed in the older window sills and window frames. This does not require you to always replace the old window frame when you are opting for the single glazed windows.

- Suitable for hot and tropical climate. If you stay in the area which is famous for its hot and tropical climate, you will not require any kind of heat retention in your home. In the single pane windows, heat cannot be retained as they are in direct contact with the elements of the weather outside. That is, if you're staying in a hot and tropical climate, single pane windows are the ones which you should go for as they do not retain the heat. This is where single glazing windows score over double glazed windows.

Drawbacks of single glazing:

- Lack of Insulation. The level of insulation which is provided in single glazing windows is almost non-existent. Sooner than later, the environment outside will start impacting the temperature inside. Unless and until there is strong climate control system, the temperature, as well as the weather conditions, will be reflected inside your home. That is why; the level of insulation which is provided is pretty limited.

- No Noise protection. Moreover, since it consists of only a single pane of glass, any noise generated outside or in the vicinity will penetrate through it more easily. That is why it will not insulate against the noise produced outside.

- They are less sturdy ie. they are easy to break . Thus they can shatter on impact. That is why the level of security which is provided is not the same as double glazing.

Thus we can say that single glazed windows might provide with some advantages but overall, they are not that energy efficient.

2.3 Double glazed system

Double glazed system consists of two glass panes which separates the outside environment with the inside of the building which can be seen from Fig 2.3. The space in between the 2 glass panes is either filled with air or inert gas or a tight vacuum. Due to the presence of this space, an extra level of insulation is provided. Double-glazing is increasingly in use in hot climate region as it provides an appropriate level of daylight penetration to the indoor environment and reduces artificial light consumption but avoiding excessive luminance and unwanted glare. Different types of double glazed system are:

- Double glazed system with air sealed cavity

  In this type of glazing system two glass panes are incorporated with air. Using multiple panes of glass incorporated with air-sealed cavities makes it possible to increase the window insulation significantly. The presence of spacers holds the glass panes apart, accommodates thermal stress, and in addition, provides moisture barrier and gas-tight seal.

- Double glazed system with Gas-filled cavity

  In this type of glazing system instead of air multiple panes of glass is incorporated with inert gas like krypton or argon or both the gases. In summer, buoyant-induced air currents within the double glazing cavity carry absorbed heat to the window top along the outer pane and consequently, a cool pool developed at the bottom end of the inner pane [37]. Filling the space with a less conductive and more viscous inert gas can minimize the scale of thermal convection and conduction and thus improve the overall insulation characteristics and also they are non-toxic, nonreactive, clear, and odorless. The optimal depth of cavity for an argon-filled window is found relatively the same as for air, i.e. around 12.5 mm. Krypton has better thermal performance and thus makes the window thinner, although it is more expensive. A mixture of krypton and argon gases can be a compromise between performance and cost. If advanced low-e coatings are employed, the radiative surface-to-surface heat transfer can be reduced to below 0.1 W/m^2 K. The heat transfer at the gas-filled cavity is then dominated by gaseous conduction and convection [38].

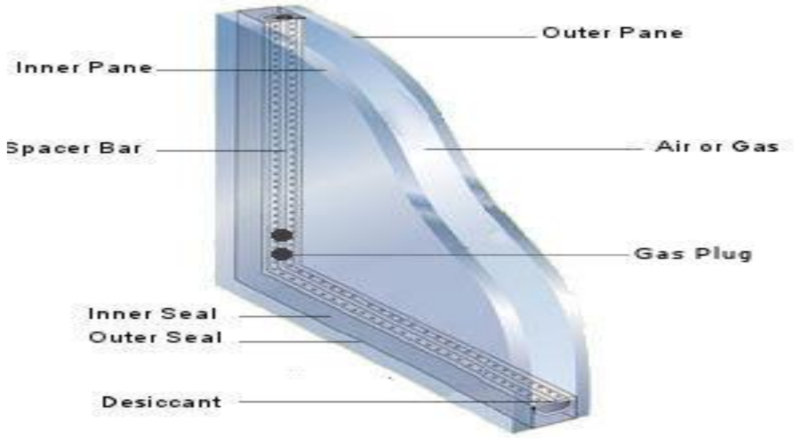


Fig. 2.3 Double glazed system with air or gas sealed cavities

- Evacuated windows

An evacuated window consists of two glass panes separated by a narrow vacuum space of around 0.12 mm which can be seen in Fig 2.4. The depth of this separation can be maintained by means of a regular array of support pillars, typically 0.32 mm in diameter, and distributed at a grid spacing of 25–40 mm. The pillar material, like stainless steel, possesses high compressive strength and low-conducting characteristics [39]. The mechanical strengths of the glass panes and edge seal are to be sufficiently strong against thermal stress and wind loads. Current technology allows edge seal employing indium wires and epoxy resin be formed at low temperature (< 200ºC) [40, 41]. The ratio of the heat transfer through the edge seal to that through the whole evacuated glazing varies with the window dimensions. A thermal transmittance of 0.4 W/m^2 K is achievable for double-vacuum glazing of 1 m^2 area [38].

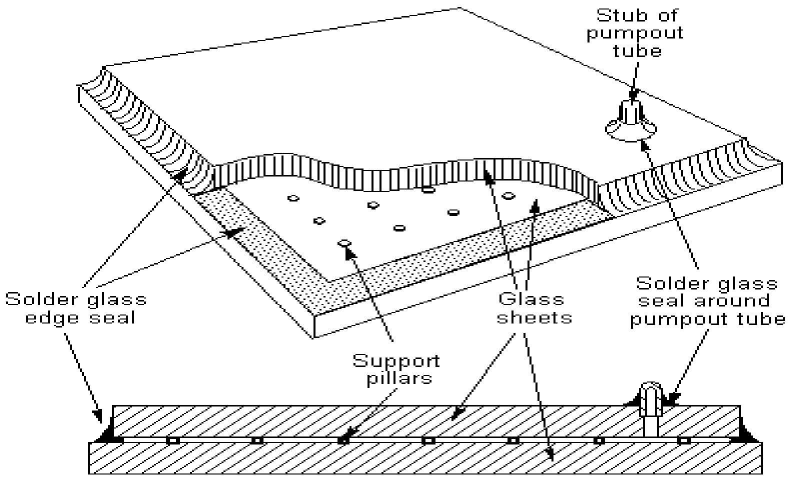


Fig. 2.4 Evacuated glazed system

Some of the reasons why double glazed windows are better than single glazed ones include:

- Proper Insulation- One of the main advantages of double glazed windows is the insulation layer which is provided between 2 glass panes. It can be vacuum or filled with inert gas. In both of these cases, it acts as a barrier between the outside elements of weather and the environment inside.Thus, the level of insulation which is provided in double glazed windows is on the higher side. This ensures that the temperature inside or the environment inside is protected to a large extent from the elements of weather. Thus, when you're heating up your home during the winter, the temperature inside will not fall drastically due to the insulation layer of the windows and also reducing cooling load in summer.

- Energy Efficient- It is easier for the climate control system in a building to maintain proper temperature irrespective of the weather outside. This is because the inner glass pane is not exactly at the temperature which is prevailing outside. It is in contact with the air inside and is around the room temperature. This ensures that the climate control system is not required to work overtime in order to maintain the temperature.

  When the climate control system is able to maintain the temperature easily, the thermal efficiency increases. As the thermal efficiency of building increases, the energy required to maintain the temperature goes down. This will help in saving on maintenance costs as well as electricity costs.

- Reduction of Noise- Double glazed windows help in cutting out the noise present outside. This ensures that building remains much quieter and calm. The sound of traffic, as well as any work in progress nearby, is eliminated to a larger extent due to the extra insulation provided by double glazed system.

- Higher margin of safety- With the extra glass pane these windows are much more secure. They are harder to break into. Moreover, they can handle a higher amount of impact as well. Thus, the wear and tear is pretty limited in these windows. Moreover, they provide a high margin of safety due to the fact that they are much more sturdy and strong.

2.4 Coated glazed system

In coated glazed system there is coating present in between two glass panes ie. at one side of glazing inorder to make the building more energy efficient than the single glazed system and the double glazed system can give. This coating can also enhance the efficiency of a building by adding coating (low-emissivity) and reflective coating in double glazed system and single glazed system inorder to increase the reflectivity of window.

Different types of coated glazed system are:

- Reflective glazed system

  Reflective glazing has coatings typically added to the surface of glazing panes that have a higher reflectivity than standard glass. The reflective coating, usually consisted of thin metallic or metal oxide layers and it comes in various metallic colors such as bronze, silver, or gold. The SHGC varies with the thickness and reflectivity of the coating, and its location in the glazing system. While some reflective coatings must be protected by sealing in cavity, others are durable and can be added on exposed surfaces. The presence of the coating changes very little the U-factor. Hence in achieving a higher reduction in solar gain a reflective coating can be added to increase the reflectivity of the glass surface. The reflectivity can be tuned to selectively:

  a. reflect short-wave solar radiation, or
  b. reflect long-wave heat radiation.

  The reflective ability depends on the particular coating and on the orientation of the glazing. High-reflectivity coatings generally have low light transmission properties, but reflective glazing systems with lower reflectivity and higher light transmission properties are also available for domestic use. Reflective coatings may be added to tinted glazing to further enhance the solar control performance of the glazing. The reflection is typically towards the side with brighter illumination, so at night, the direction of the reflectivity can change so that the reflection is to the interior.

- Low-emissivity glazing system

  Low-emissivity (low-e) refers to a low emissivity over the long wavelength portion of the spectrum. Low-e coatings in colors of gold, silver or copper offer a range of solar control characteristics. A typical coating (of thickness around 0.1 mm) has three layers, i.e. a thin metal layer sandwiched between two dielectric layers.

  Low emissivity (low-e) means that the window glazing radiates or emits only a small fraction of the incident thermal radiation that strikes its surface. Depending on where the low-e coating is applied a window can be configured to either:

a) Minimize the amount of solar heat coming into a home or
b) Maximize heat retention

From Fig. 2.5 it can be said that for a cooling dominated (hot) climate, the low-e coating should be on the inward facing surface of the outer pane (Surface 2). This allows the window to reflect most of the unwanted heat from sunlight, reducing the overall heat gain. In heating dominated (cold) climate, the goal is to reflect or re-radiate as much heat back into the home, so the low-e coating should be on the outward facing surface of the inner pane (Surface 3). There are two basic coating techniques: pyrolytic and sputtered. In pyrolytic coating, metallic oxide is deposited directly onto the glass surface when it is still hot. The result is a hard surface layer with good durability. The low-temperature sputtered process produces soft coats that can be deposited both on flat glass sheets and thin plastic films. But they are less durable and should be protected against humidity and physical contact [42].

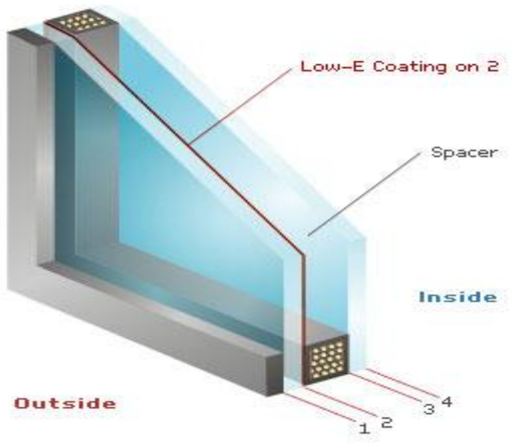


Fig 2.5 Schematic view of Coated glazed system (low-e)

Thus we can say that coated glazed system is superior to the other two glazed system discussed above but the only disadvantage this system has is that it is very costly.

2.5 Smart glazed system

Smart windows are essentially ''variable tint'' glazing. They make use of chromogenic technologies to change optical properties in response to external stimulus. Examples are: electrochromic (EC), which responds to electrical voltage or charge DC powered, suspended particle devices (SPD) AC-powered thermochromic (TC), which responds to temperature, photochromic (responding to UV light), and gasochromic (responding to reducing or oxidizing gases) [43,44]. Amongst these, the EC technology is most mature with commercial products available [45].

- Electrochromic (EC) coating, typically about 1 mm thick, consists of five layers on glass substrate. A thin metallic coating of nickel or tungsten oxide is sandwiched between two transparent electrical conductors, through which a distributed electrical field is set up when a voltage is applied. The glazing switches between the clear (bleached) and fully colored (transparent prussian bluetinted) states with little degradation in view, and can be modulated to any intermediate state as well. Fig. 2.6 shows the schematic view of electrochromic glazing system. The switching action requires only low-voltage power (0–10 V DC). The upper and lower limits of visible transmittance are within the ranges of 0.50–0.70 and 0.02– 0.25, respectively. The switching speed is tied to the size and temperature of the window, typically longer for coloring than bleaching. The SHGC ranges from 0.10 to 0.50. At the fully colored state, its energy performance is similar to the tinted glazing. At present, there have been studies suggesting that EC windows cannot provide full control of uncomfortable direct sunlight effects, such as disability glare and high-luminance spots [46, 47]. Other concerns that hinder its commercialization include long switching time (in the order of minutes), inadequate colour rendering, uncertain reliability and high investment.

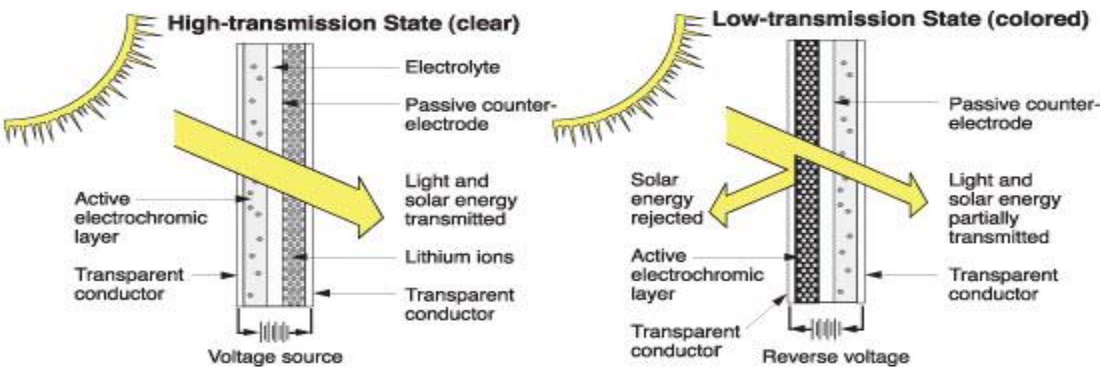


Fig. 2.6 Schematic view of Electrochromic glazing system

- A suspended particle device (SPD) switchable glazing changes its state from opaque to transparent in the presence of a power supply. Electrically-actuated SPD glazing can provide control of solar heat gain and glare in building fenestration applications [48, 49]. SPD glazing is almost opaque without the application of power supply and transparent when, AC power supply is applied. Fig. 2.7 shows the schematic view of the SPD glazing system. An SPD glazing will have intermediate transparency, for the particular example chosen, between 5–55% when the applied AC voltage is set between 0 and 100 V [50,51]. The day lighting and thermal performance of an SPD glazing showed that SPD glazing is superior over other glazing applications in building [49, 50].

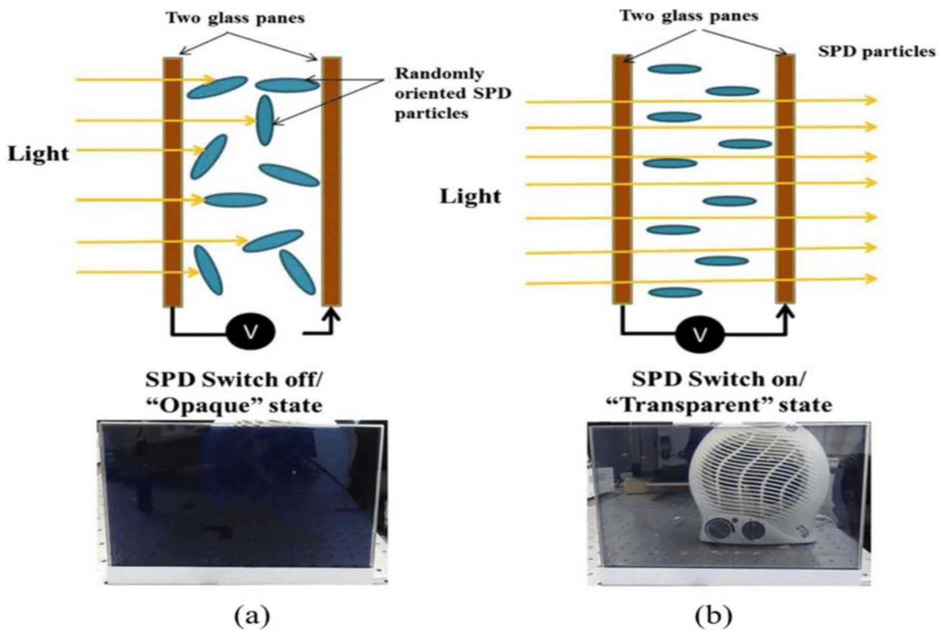


Fig. 2.7 Schematic view of SPD glazing system

- Thermochromic (TC) glazing System consist of a thin film polymer or inorganic coating on glass that switches passively from a clear to tinted state in response to glass surface temperature (transparent in all states).Fig. 2.8 shows the schematic view of thermochromic glazing. Like photochromic glazings, which switch based on amount of incident light, these passive technologies offer variable solar-optical properties without the need for power or controls. The transition or critical temperature can be tuned by the material composition; some devices switch over a very narrow range of temperatures (which can have a variegated appearance if the window is non-uniformly irradiated) while others exhibit thermochromic behavior over a broad range of temperatures [43]. Thermochromics typically exhibit absorption in the visible range (380-780 nm) when switched.

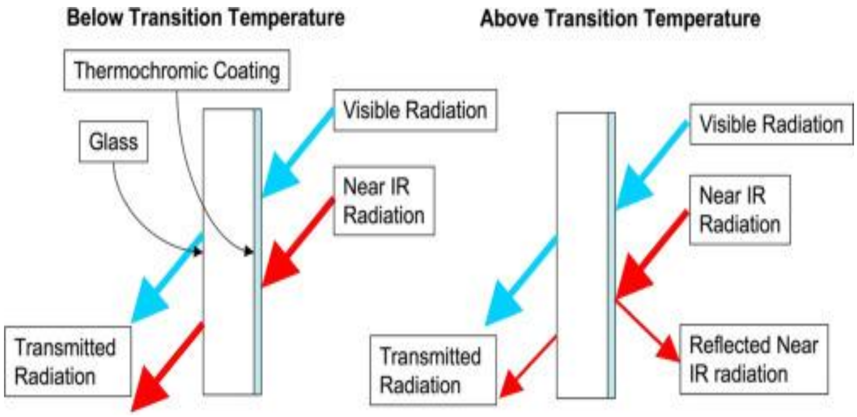


Fig 2.8 Schematic view of Thermochromic glazing system

- Gasochromic glazing system consists of thin film which is similar in principle to EC glazings in that it switches reversibly from a clear to tinted transparent state but in this it is activated by the insertion and removal of a gas into the air cavity between the two layers of glass [52]. Exposure of the film to hydrogen gas causes the thin film to tint and exposure to oxygen causes H_2O to form and the film to bleach. Fig 2.9 shows the schematic view of Gasochromic glazing system. The film switches much faster than EC coatings but exhibits a lower contrast ratio (ratio of bleached to colored state) compared to EC glazings. Activation requires careful proper implementation of the gas insertion and extraction process over the broad hot-cold cycling of temperatures that windows are subjected to. To improve thermal performance, the dual-pane gasochromic must be combined with a third glass layer with a sputtered low-emittance coating, whereas with EC windows, the low-e properties can be incorporated within the dual-pane unit. There are a few commercial products currently available in the European Union. Complexity of installation may be a significant market barrier for this type of glazing system.

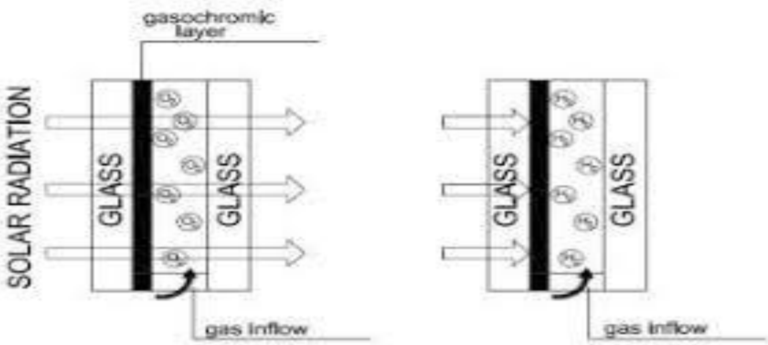


Fig.2.9 Schematic view of Gasochromic glazing system

Chapter: 3 Glazing Materials

3.1 Introduction

A window's thermal performance is largely established according to the glazing material used and its properties. It is possible to divide the various glazing materials according to:

- Transparency (totally transparent or selectively opaque to various types of radiation and wavelengths)
- Material (glass, polycarbonates, fiberglass, acrylics, etc.)
- Cross-section of the element (one layer, two layers with air space in between, etc.)

In recent times, clear glass has been the principal glazing material, mainly for windows. Although glass is resilient and allows a high percentage of sunlight to enter buildings, it has little or no resistance to heat flow. Most architects opt for glass, sandblasted, frosted, or etched as their first choice for glazing. With certain budget constraints, such an extravagant option tends to take a backseat and that is where different types of glazing materials come into the picture. Many types of alternate glazing materials have been developed and these new generation of materials propose improved window efficiency and performance for consumers. While this new generation of glazing materials is fast gaining popularity in the market, the search for more efficient technologies continues. Different types of glazing materials have come to the fore as more and more architects and designers realize the need to install energy efficient materials. No one type of glazing satisfies all applications. Many alternate materials like polycarbonate (PC), polyethylene (PE), acrylic, fiberglass, and PVC are available those serve different purposes

3.2 Types of Glazing Material

a. <u>Regular Transparent Glass</u>

This is the most common type of glazing used for glazed building openings. The thickness of sheet of glass usually ranges between 3 and 5 mm. This type of glazing permits high proportion of visible light penetration (88-90%) as well as penetration of a large proportion of the solar radiation striking it (77-86%). These properties make it the preferred material for south facing windows and greenhouses. It is important to remember that the thermal resistance coefficient of glass is very low ($R = 0.18\ W/^{o}C\ m^2$), which makes the glazing a thermally weak point in the structure's envelope.

b. Double Glazing

This consists of two sheets of glass with space in between, sometimes filled with air or other gases, or vacuum. The thickness of both the glass and space are variable. These variations have a certain effect, up to a certain limit, on the percentage of radiation allowed to penetrate and on thermal conductance of the composition (when the thickness of the air space is over 2.5 cm, its marginal effect becomes smaller). The main advantage of this type of cross-section is its ability to reduce heat transfer from one pane to the other, both by conduction and by radiation. Double glazing is more expensive than single glazing but sometimes offers improved performance. Triple glazing (sometimes used) is even more expensive and has a conductance coefficient that is about 20% lower than that of double glazing, but the savings in energy are relatively small compared to its higher cost.

c. Absorbing Glass

This type of glazing permits penetration of light (about 80%, depending on thickness), but transmits only a relatively small portion of total solar radiation at the different wavelengths striking it (48-65%). The various industrial products belonging to this group are usually made of two layers of glass with a layer of absorbing material between them or of glass coated with one of the various varnishes. These additions absorb different wavelengths of radiation (from ultraviolet to infrared) and their effectiveness varies. Absorbing glass significantly prevents fading of colors, moderates light penetration into the room and reduces overall radiation. However, absorbing the radiation in the glass will raise its temperature, and its heat will be transferred by convection to the air of the building's interior.

d. Dark Glass

This type of glass reduces both the light and the radiation penetrating it, but a relatively large amount of radiation is absorbed by the glass causing the temperature of the glass surface to rise. In this way the glass itself becomes a source of heat emitted to the room. Dark glass could be a solution for buildings which require maintaining a certain filtration of penetrating daylight while also retaining large openings.

e. Reflective Glass (mirror)

This material will most significantly reduce penetration of radiation from the reflecting side to the non-reflecting side (penetration of 11-37% of total striking radiation). Such glazing could be used in cases where it is desirable to maintain eye contact with the outside as well as to prevent penetration of radiation (for example, when there is a view on the west side of a building and a western window is not desirable) or in areas where it is hot most days of the year. However, it should be kept in mind that the high level of reflected light could become a nuisance to nearby buildings and to people in adjacent open areas. The reflected radiation could cause a rise in the temperature of areas it strikes (walls of nearby buildings, paved areas) and also glare. Orienting reflective glass towards a road could become a safety hazard.

f. Polycarbonate (PC)

Of the entire glazing materials available today, clear, high-impact resistant polycarbonate material offers the widest range of properties. The advantages of PC are its clarity, safety, security, energy savings and the designing freedom, it offers to the architects. It is available in various sizes and configurations, the most important ones being single layer and multi-layer sheets.

The advantage of using this kind of material is that it is one of the toughest carbonate sheets available, about 300 times stronger than the glass. These can be joined mechanically, solvent bonded and welded. PC also has excellent resistance to dilute acids and mineral oils and fairly good resistance towards alcohol and vegetable oils. The life expectancy is about 10 years and they have a maximum working temperature of 250 ºF. The PC sheets are about half the weight of comparative glass products and are mainly used for flat glazing applications that require high abrasion and impact resistance.
Polycarbonate is mostly used for window glazing, greenhouse glazing, space shuttle windows, astronaut visors and industrial eye protection. It is available in various colors like clear, opal, grey and bronze. Besides its application as an alternate to glass for glazing, PC also finds applications in store fonts, signage, display cases, newspaper type racks and security barriers.

g. Acrylic:

Acrylic sheet is made up of thermoplastics and has very good weather resistance. It is five times stronger than glass but can easily be scratched. Acrylic is relatively easy to bend around large-diameter curves and has a lifespan from 10 to 30 years. At present it is not as common as it used to be but it’s still available as a single- or double-walled material. It brings many advantages as an alternative to glass like it offers excellent optics, is light in weight and it’s easy to fabricate. It resists breaking and inherently has a higher level of U.V. protection. Acrylic has a light penetration of 92% for sheets 30 mm thick. It can be easily heat-formed without losing its clarity.

It is used for glazing in industrial plants, schools and other institutional buildings where there is a high breakage rate and also in workshops, glasshouses, outhouses, playhouses. It is also used for windows and window replacement glass. Besides the colorless transparent sheet, acrylic is also produced in a great variety of transparent, translucent and opaque colors and in a variety of surface patterns.

h. <u>Corrugated fiber glass</u>

It is available in different hues and thickness. In any case, it does not permit eye contact with the outside and its physical deterioration is quite fast. This material is available in clear, dark or white varieties. Typical FRP Corrugated Fiberglass Panels come in a translucent color of clear, white or green to allow light transmission flow into any building or sky lighting your roofing application. Fiberglass reinforced polymer (FRP) corrugated panels remain virtually unaffected in many chemical environments. These Corrugated Fiberglass panels are strong, durable, shatter resistant and will not rust, rot, scale or mildew. These panels are commonly specified for use as roofing and siding by industrial engineers.

3.3 Properties of Glazing Material

Energy transfer through the glazing materials mainly depends upon the properties of the glass which are given below:

- Optical properties of the glass
- Thermal properties of the glass

3.3.1 Optical Properties

Solar radiation includes both direct and diffused radiation incident in the glazing which is partly reflected and partly transmitted through the glazing. Some fraction is absorbed by the glazing also.

The fraction of radiation which will be reflected, transmitted or absorbed are denoted by

a) Transmittance (τ)
b) Reflectance (p)
c) Absorptance (α)

- Transmittance (τ): This refers to the percentage of radiation that can pass through glazing. Transmittance can be defined for different types of light or energy, e.g., visible transmittance, UV transmittance, or total solar energy transmittance. Transmission of visible light determines the effectiveness of a type of glass in providing daylight and a clear view through the window. For example, tinted glass has a lower visible transmittance than clear glass. More than half of the sun's energy is invisible to the eye. Most reaches us as near-infrared with a few percent in the ultraviolet (UV) spectrum. Thus, total solar energy transmittance describes how the glazing responds to a much broader part of the spectrum and is more useful in characterizing the quantity of total solar energy transmitted by the glazing.

- Reflectance (p): This refers to the percentage of radiation that is reflected back from the surface of glazing. The natural reflectivity of glass is dependent on the type of glazing material, the quality of the glass surface, the presence of coatings, and the angle of incidence of the light. The reflectivity of various glass types becomes especially apparent during low light conditions. The surface on the brighter side acts like a mirror because the amount of light passing through the window from the darker side is less than the amount of light being reflected from the lighter side. This effect can be noticed from the outside during the day and from the inside during the night.

- Absorptance (α): Energy that is not transmitted through the glass or reflected off its surfaces is absorbed. Once glass has absorbed any radiant energy, the energy is transformed into heat, raising the glass temperature. The absorptance of glass is increased by glass additives that absorb solar energy. If they absorb visible light, the glass appears dark. If they absorb ultraviolet radiation or near-infrared, there will be little or no change in visual appearance. Clear glass absorbs very little visible light, while dark-tinted glass absorbs a considerable amount. The absorbed energy is converted into heat, warming the glass. Thus, when "heat-absorbing" glass is exposed to the sun, it feels much hotter to the touch than clear glass.

Ideally, $\tau + p + \alpha = 1$

However this is complicated by the fact that radiation incident on the surface can have non-constant distribution over the directions. So when measuring any optical property then the wavelength distribution and direction of incident radiation must be specified.

3.3.2 Thermal Properties

There are different thermal properties of glass which can determine thermal behavior of glass material and they are:

- Thermal conductivity
- Specific heat
- Emittance
- Overall heat transfer coefficient of glazing

a) Thermal Conductivity (k):

It is measure of the ability of a material to transfer heat. Given two surfaces on either side of the material with a temperature difference between them, the thermal conductivity is the heat energy transferred per unit time and per unit surface area, divided by the temperature difference.

$$Q = -kA \frac{\mathrm{dT}}{\mathrm{dx}}$$

Where Q is the rate of heat flow in positive x direction

The proportionality constant ‘k’ is the property of the material and is known as thermal conductivity.

b) Specific heat (C):

It is the amount of heat per unit mass required to raise the temperature by one degree Celsius. The specific heat can be found by the equation given below

$$Q = C.m\,\Delta t$$

Where Q is the rate of heat flow in positive x direction, m is mass, Δt is change in temperature and C is the specific heat in kilocalories.

c) Emittance

When solar energy is absorbed by glass, it is either convected away by moving air or reradiated by the glass surface. This ability of a material to radiate energy is called its emissivity (ε). Window glass, along with all other objects, typically emits, or radiates, heat in the form of long-wave far-infrared energy. The wavelength of the long-wave far-infrared energy varies with the temperature of the surface. This emission of radiant heat is one of the important heat transfer pathways for a window. Thus, reducing the window's emission of heat can greatly improve its insulating properties. Standard clear glass has an emittance of 0.84 over the long-wave infrared portion of the spectrum, meaning that it emits 84% of the energy possible for an object at room temperature. It also means that for long-wave radiation striking the surface of the glass, 84% is absorbed and only 16% is reflected. By comparison, low-E glass coatings have an emittance as low as 0.04. This glazing would emit only 4% of the energy possible at its temperature, and thus reflect 96% of the incident long-wave infrared radiation.

d) Overall heat transfer co-efficient of the glass (U value)

Overall heat transfer co-efficient refers to the measure of the heat gain or loss through glass due to the difference between indoor and outdoor air temperatures. A part of the overall thermal resistance of a fenestration system depends on the convective heat transfer between the exposed surface of the glass and the environment which is represented by U value and a lower U-value indicates better insulating properties.

Chapter 4: Experiment and Result

4.1 Introduction

There are various kinds of glazing materials which are used for windows like plain transparent glass, different kind of colored tinted glass, tinted glass with coating in it etc. These colored glasses actually contain different minerals and their oxides which give them various colors. Tinted glass products are produced by small additions of metal oxides to the float glass. These small additions color the glass bronze, green, blue or grey but do not affect the basic properties of the glass except for changes in the solar energy transmittance. The color is homogeneous throughout the thickness and as the coating is added to this tinted glass on either side then reflectance also changes and thus the absorptance also changes.

Most float glass products contain small amounts of iron oxide which produce a green tint usually only perceived when the glass pane is viewed 'on edge'. Additional iron oxide is introduced to produce green tint, cobalt oxide for grey tint and selenium oxide for bronze tint. To produce a blue tint additional cobalt oxide is added to the float glass composition. Due to different transmissivity, reflectivity and absoptivity the surface temperature also varies. So by studying the variation of transmittance and reflectance of radiation with wavelengths we can predict the performance of different glass.

4.2 Instrument used

Two kinds of spectrophotometer were used during this experiment. They are:

- Perkin-Elmer Lambda-35 Spectrophotometer
- Jasco V-770 Spectrophotometer

Fig 4.1 shows the overall setup used for measuring spectral transmittance and spectral reflectance using Perkin-Elmer Lambda-35 spectrophotometer and Fig 4.2 shows Jasco V-770 Spectrophotometer which was used. Fig 4.3 and Fig 4.4 shows setup used in Perkin-Elmer Lambda-35 for measuring spectral transmittance and spectral reflectance respectively

Fig 4.1 Perkin-Elmer Lambda-35 spectrophotometer

Fig 4.2 Jasco V-770 Spectrophotometer

Fig 4.3 Setup for measuring spectral transmittance

Fig 4.4 Setup for measuring spectral reflectance

4.3 Procedure

a. Sixteen different kind of glass samples are taken which are tinted and having coating on one side of the glass (inside part) and these glass samples were provided by Saint Gobain each having size of 6.5 x 5.5 x 0.7 cm. From Fig. 4.5 we can see the samples which were used in experiment.

b. All the glass samples were cleaned carefully using acetone and propanol.

c. The spectrophotometers were set to UV - VIS mode for Perkin-Elmer Lambda-35 Spectrophotometer and UV – VIS – NIR mode for Jasco V-770 Spectrophotometer . The range of wavelength is chosen from 190 nm to 1100 nm while using Perkin-Elmer Lambda-35 Spectrophotometer and for Jasco V-770 Spectrophotometer range of wavelength is from 200 nm to 2500 nm.

d. Air is used as reference for measuring spectral transmittance and a standard sample is used as reference for measuring spectral reflectance in this experiment.

e. Now keeping air as standard, each glass sample is put appropriately in the stand one by one. The transmittance of samples which were measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incident angles varies from 0^o to 85^o and for Jasco V-770 Spectrophotometer, transmittance of samples which were measured in visible and infrared wavelength were at a fixed incident angle.

f. Now for measuring spectral reflectance first we use standard sample and then we put each glass sample appropriately in the stand one by one. The reflectance of samples which were measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incident angles varies from 15^o to 75^o and for Jasco V-770 Spectrophotometer, reflectance of samples which were measured in visible and infrared wavelength were at a fixed incident angle.

g. The data for transmittance and reflectance at corresponding wavelength are obtained using software in PC interfaced with the Spectrophotometer and graph is plotted from this data using grapher software.

h. From the measured spectral data, solar optical properties are determined using the recommended methods of British Standard (BS EN 410) [28] and graph is plotted using grapher software.

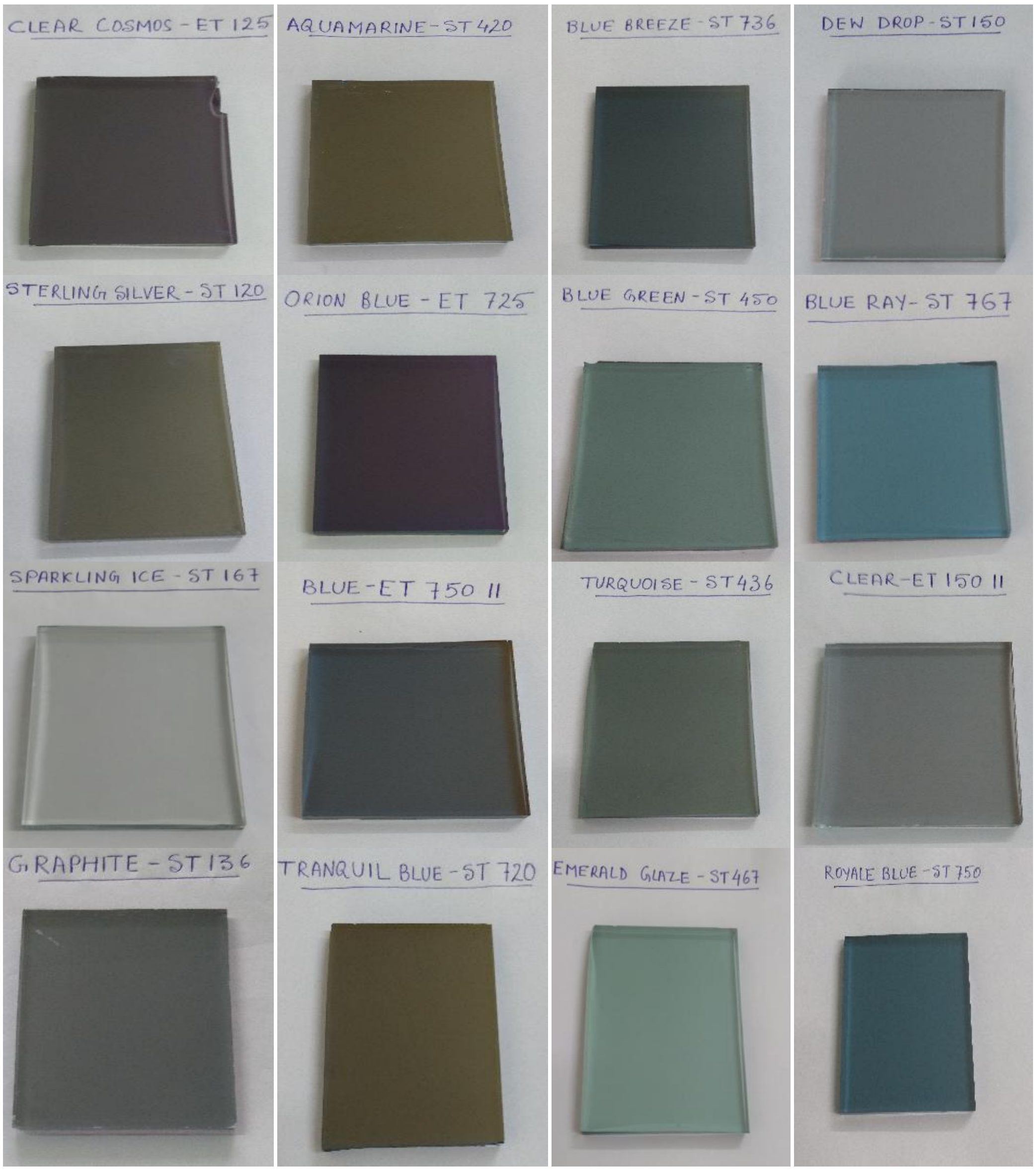


Fig 4.5 Glass samples used for experiment

4.4 Results and Discussions

The set of spectral data which are obtained from the experiment is plotted in the form of graph and shown from Fig. 4.6 to Fig. 4.81. Fig. 4.82 to Fig. 4.145 shows graphs which are determined using the recommended method of British Standard (BS EN 410) from the measured spectral data.

Glass Manufacturer: Saint Gobain
Sample: Cool-Lite Sterling Silver ST 120 Non-coated side

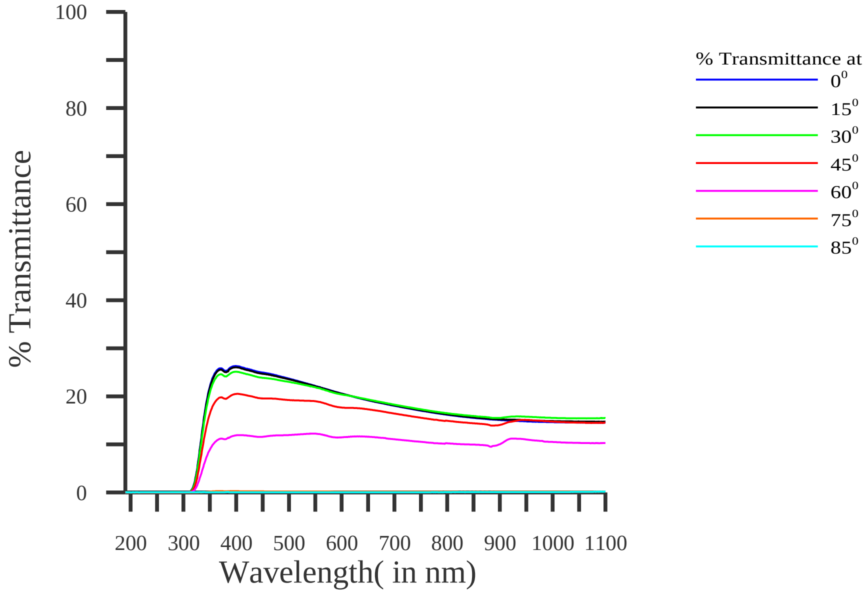


Fig 4.6: % Transmittance vs Wavelength for non-coated side of sample ST 120

Glass Manufacturer: Saint Gobain
Sample: Cool-Lite Sterling Silver ST 120 Coated side

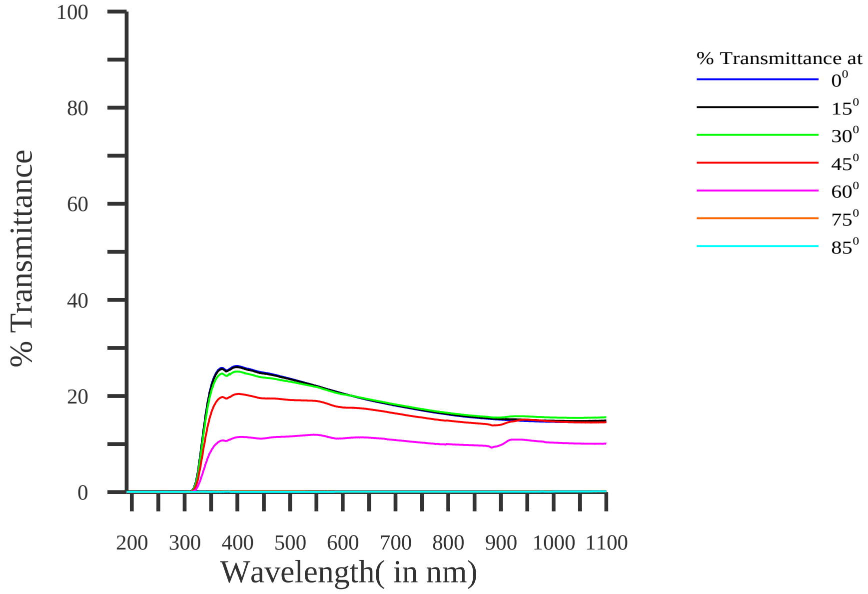


Fig 4.7: % Transmittance vs Wavelength for coated side of sample ST 120

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 400 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.6 and 4.7. The transmittance of Fig.4.6 and Fig.4.7 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incidence angles varying from 0^0 - 85^0. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

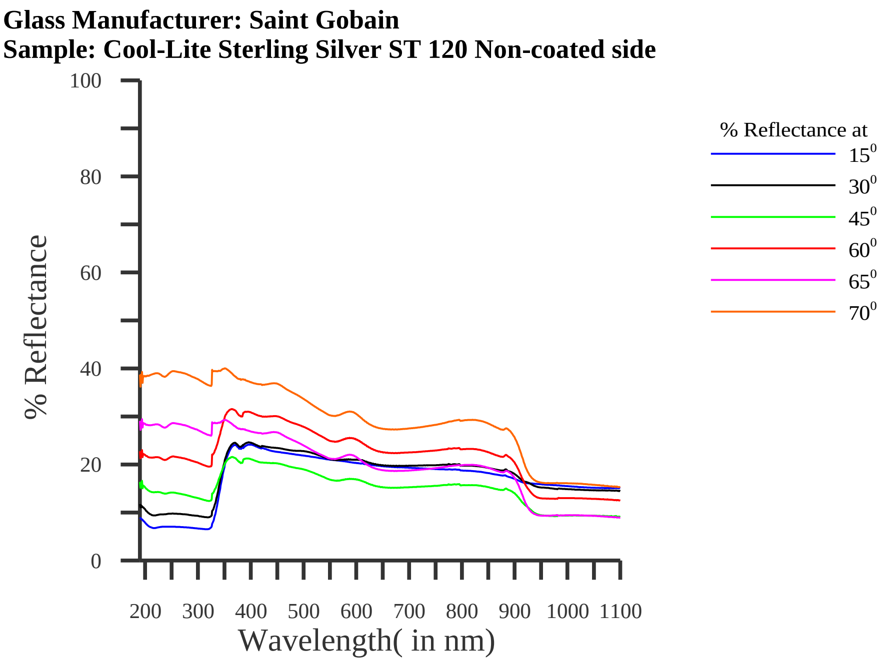


Fig 4.8: % Reflectance vs Wavelength for non-coated side of sample ST 120

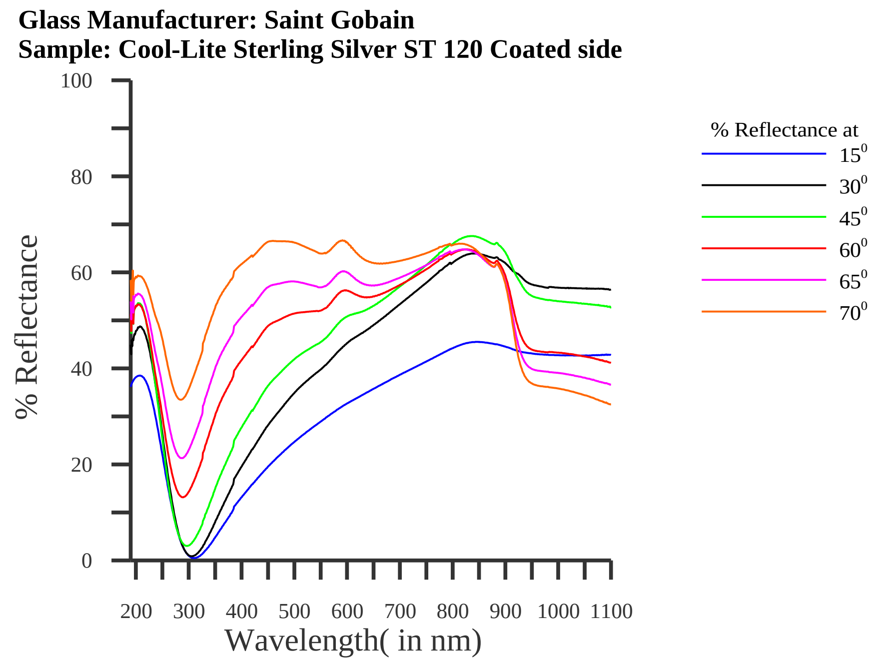


Fig 4.9: % Reflectance vs Wavelength for coated side of sample ST 120

The reflectance is increased with the increase of incidence angle except for 45^0 and 65^0 as seen in Fig 4.8. The coating on the other side of the sample could be the reason for this exception. The nature of the curve shows a sharp increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.8.

From Fig. 4.9 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve shows sharp decrease for shorter wavelength and then gradually increases till 850 nm and then gradually decreases. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and high reflectance at shorter wavelength because of coating on this side of glazing sample. The reflectance of Fig. 4.8 and Fig.4.9 are measured by Perkin- Elmer Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

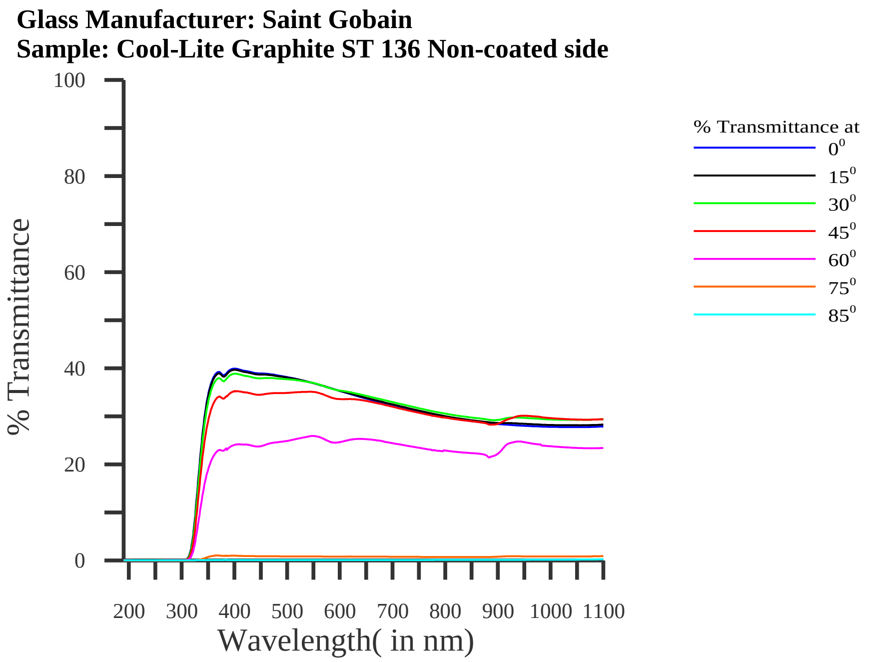


Fig 4.10: % Transmittance vs Wavelength for non-coated side of sample ST 136

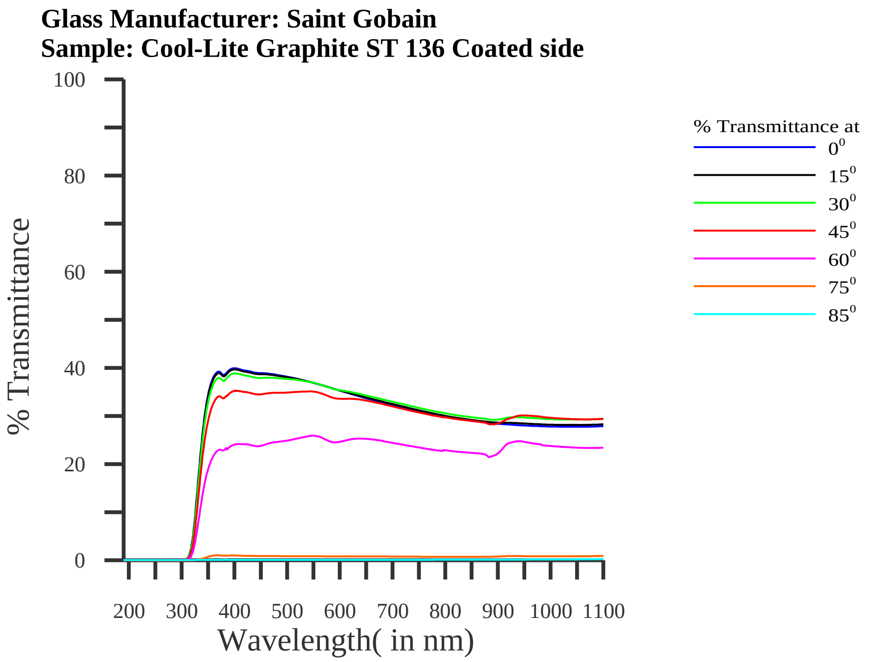


Fig 4.11: % Transmittance vs Wavelength for coated side of sample ST 136

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 400 nm and

then decreases at a slower rate with increase in wavelength as shown in Fig 4.10 and Fig 4.11. The transmittance of Fig 4.10 and Fig 4.11 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incidence angles varying from 0^0 - 85^0. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

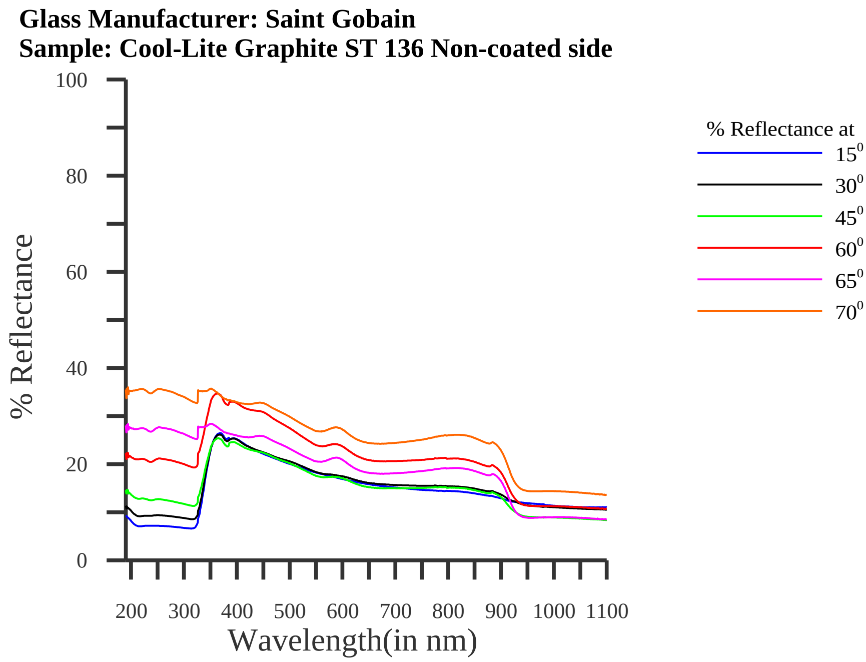


Fig 4.12: % Reflectance vs Wavelength for non-coated side of sample ST 136

The reflectance remains almost same for the incidence angle from 15^0 to 45^0 and then increases with the increase of incidence angle except for 65^0 as seen in Fig 4.12. The coating on the other side of the sample could be the reason for this exception. The nature of the curve shows a sharp increase for shorter wavelength and then decreases gradually with increase in wavelength as seen in Fig 4.12.

The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

The reflectance of above figure is measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV-vis range at incidence angles varying from 15^0 - 70^0.

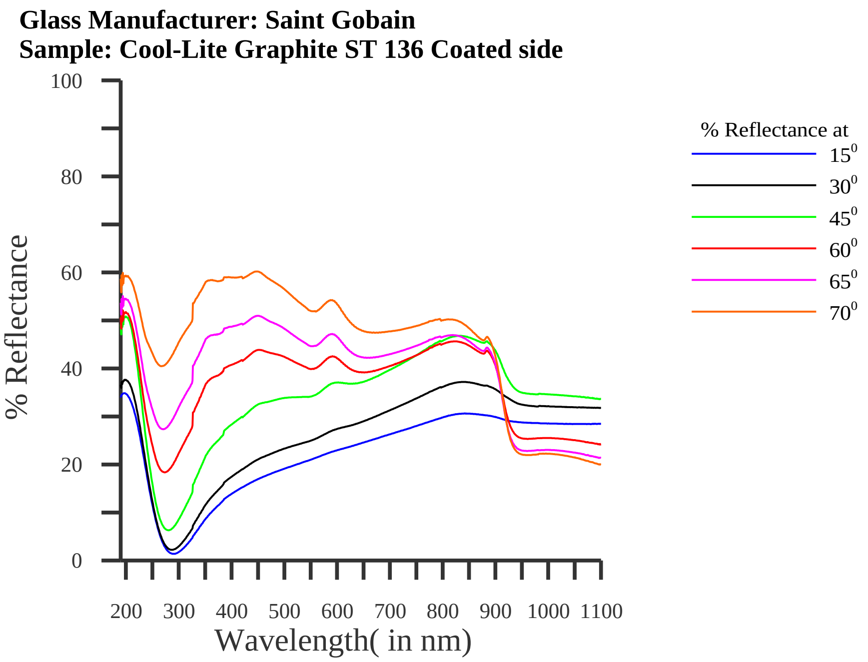


Fig 4.13: % Reflectance vs Wavelength for coated side of sample ST 136

From Fig. 4.13 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve shows sharp decrease for shorter wavelength and then gradually increases till 850 nm and then gradually decreases. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and also because of coating on this surface of glazing sample. The reflectance of above figure is measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

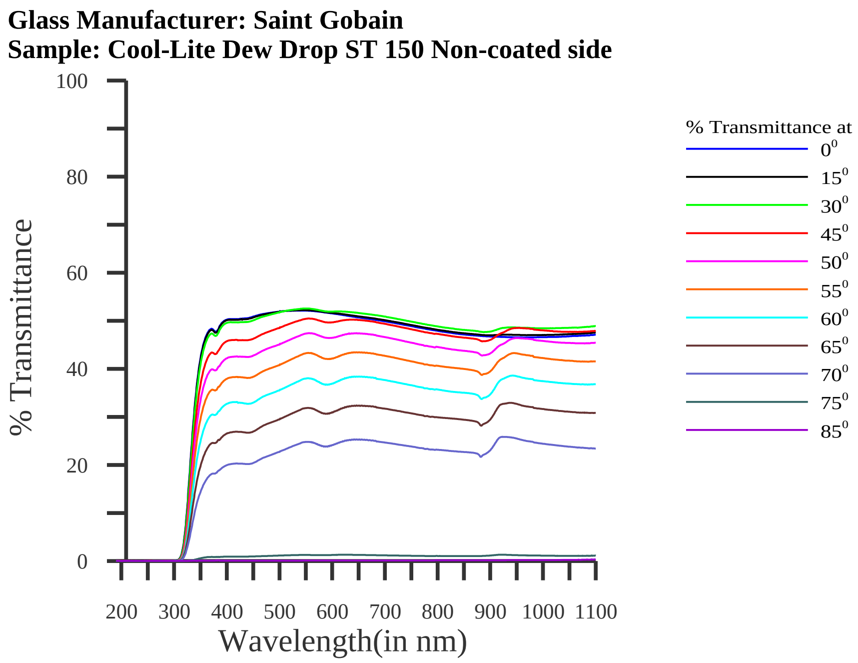


Fig 4.14: % Transmittance vs Wavelength for non-coated side of sample ST 150

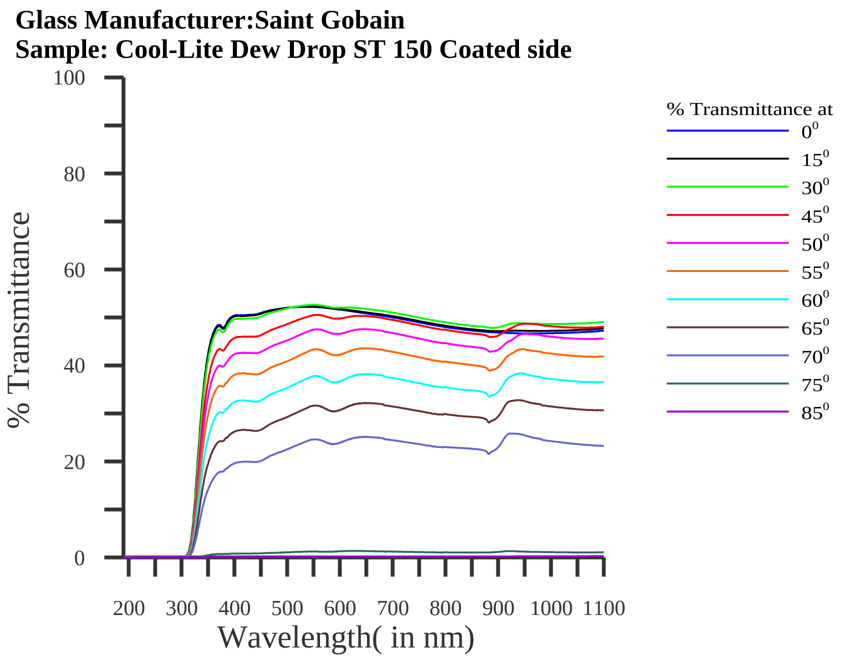


Fig 4.15: % Transmittance vs Wavelength for coated side of sample ST 150

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 400 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.14 and Fig 4.15 and transmittance are measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV-vis range at incidence angles varying from 0^0 - 85^0. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

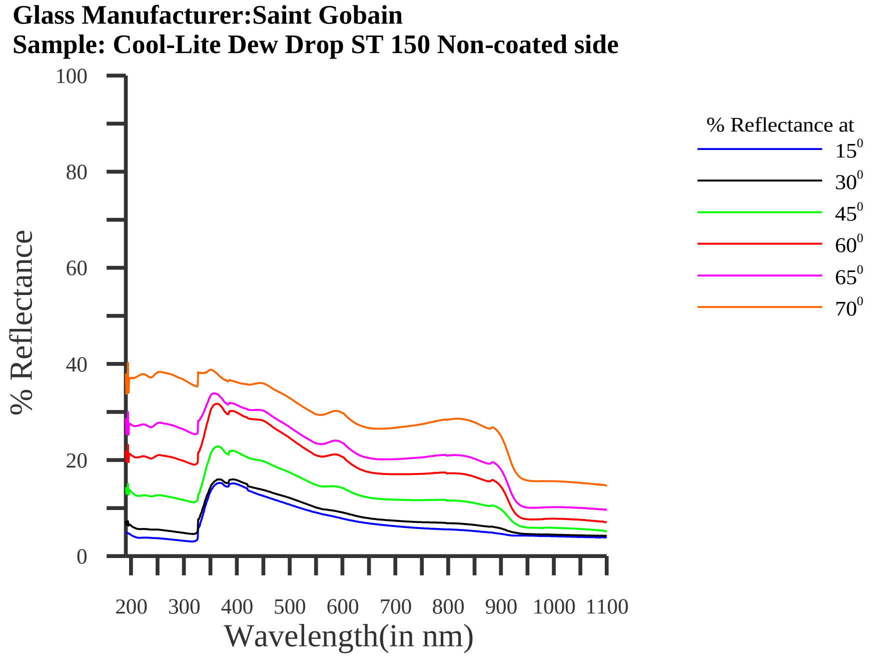


Fig 4.16: % Reflectance vs Wavelength for non-coated side of sample ST 150

The reflectance is increased with the increase of incidence angle as seen in Fig 4.16. The nature of the curve shows a sharp increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.16. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region. The reflectance of the above figure is measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

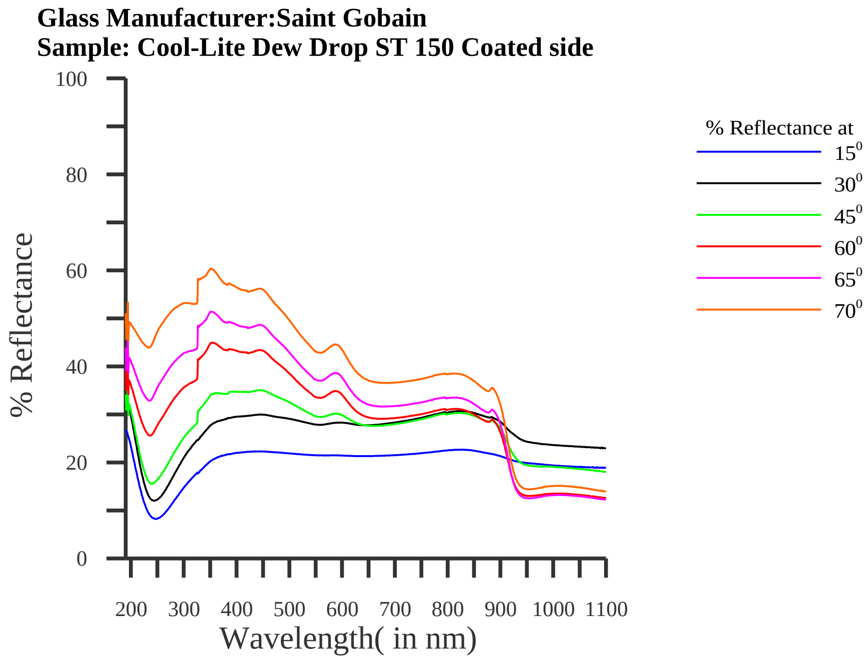


Fig 4.17: % Reflectance vs Wavelength for coated side of sample ST 150

From Fig. 4.17 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve shows sharp decrease for shorter wavelength and then sharply increases till 400 nm and then gradually decreases.

The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and also because of coating on this surface of glazing sample.. The reflectance of Fig. 4.17 is measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

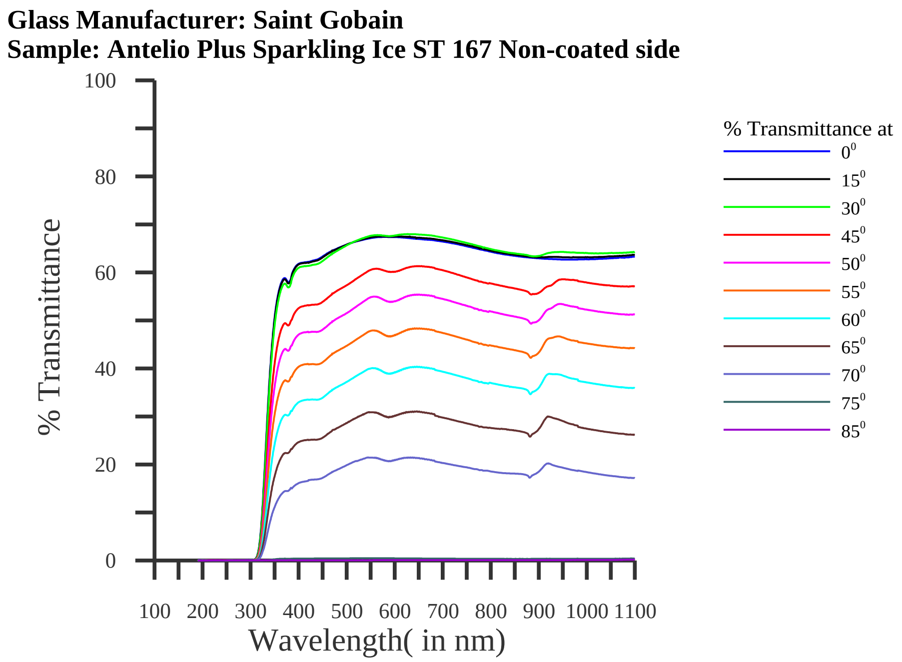


Fig 4.18: % Transmittance vs Wavelength for non-coated side of sample ST 167

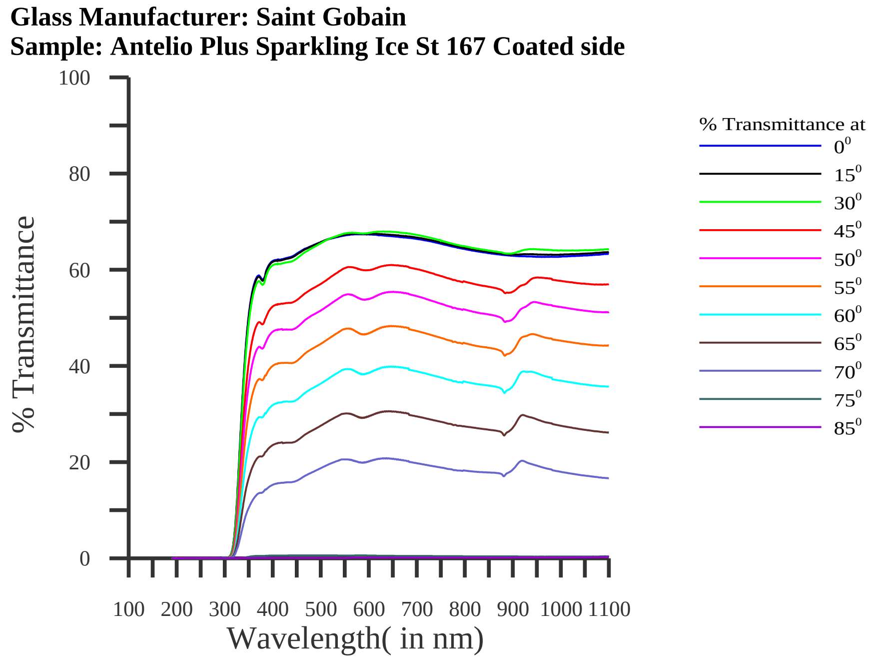


Fig 4.19: % Transmittance vs Wavelength for coated side of sample ST 167

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 500 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.18 and 4.19 and the transmittance of Fig.4.18 and Fig.4.19 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incidence angles varying from 0^0 - 85^0. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

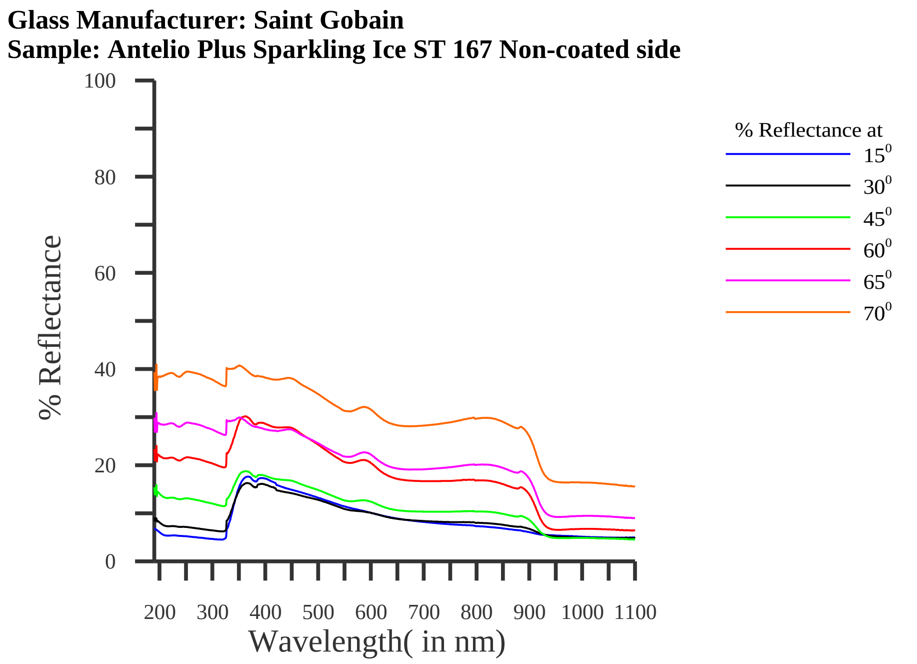


Fig 4.20: % Reflectance vs Wavelength for non-coated side of sample ST 167

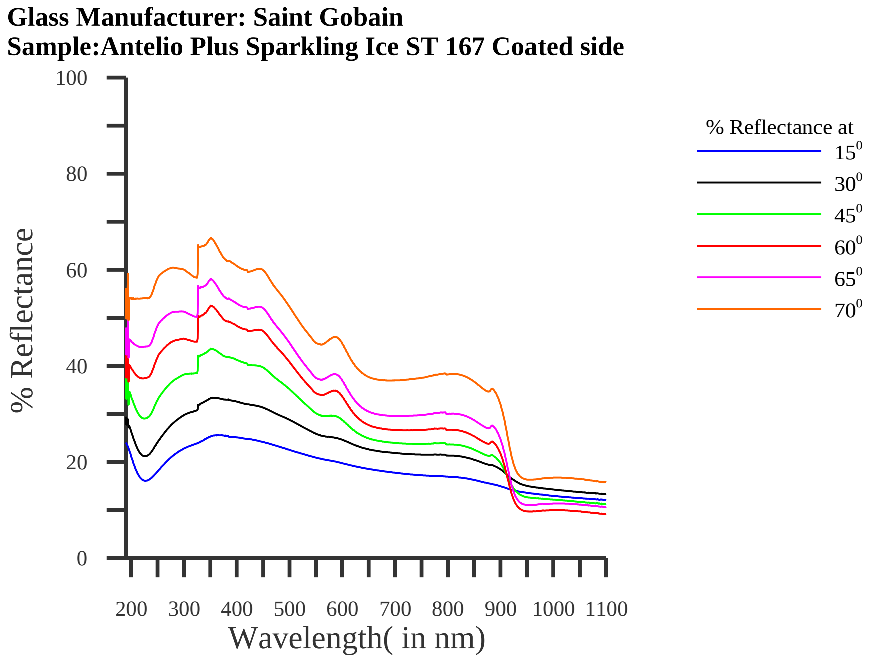


Fig 4.21: % Reflectance vs Wavelength for coated side of sample ST 167

The reflectance remains almost same for the incidence angle from 15^0 to 30^0 and then increases with the increase of incidence angle as seen in Fig 4.20. The nature of the curve shows a sharp increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.20. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region. From Fig. 4.21 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve shows sharp decrease for shorter wavelength and then sharply increases till 400 nm and then gradually decreases. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and also because of coating on this surface of glazing sample. The reflectance of Fig. 4.21 is measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

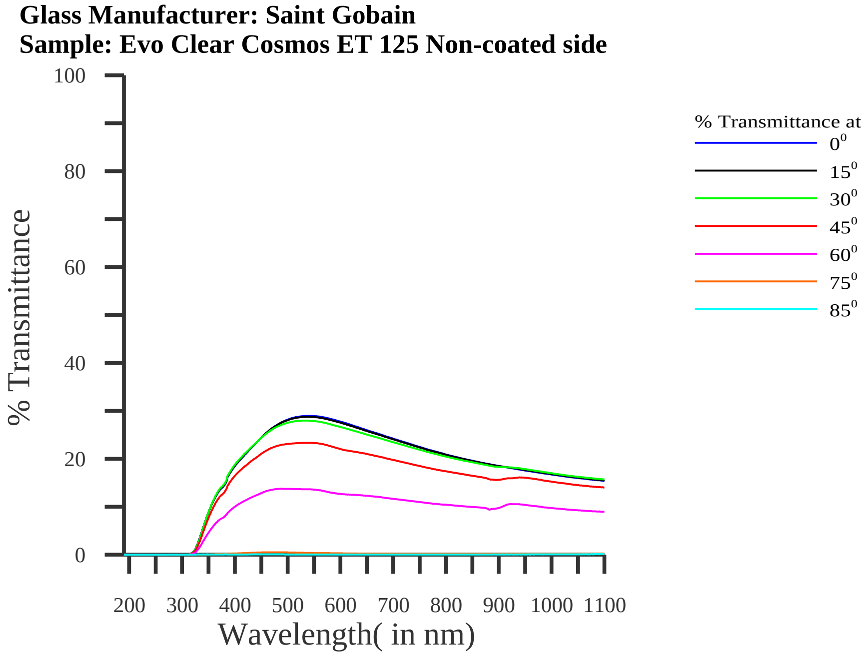


Fig 4.22: % Transmittance vs Wavelength for non-coated side of sample ET 125

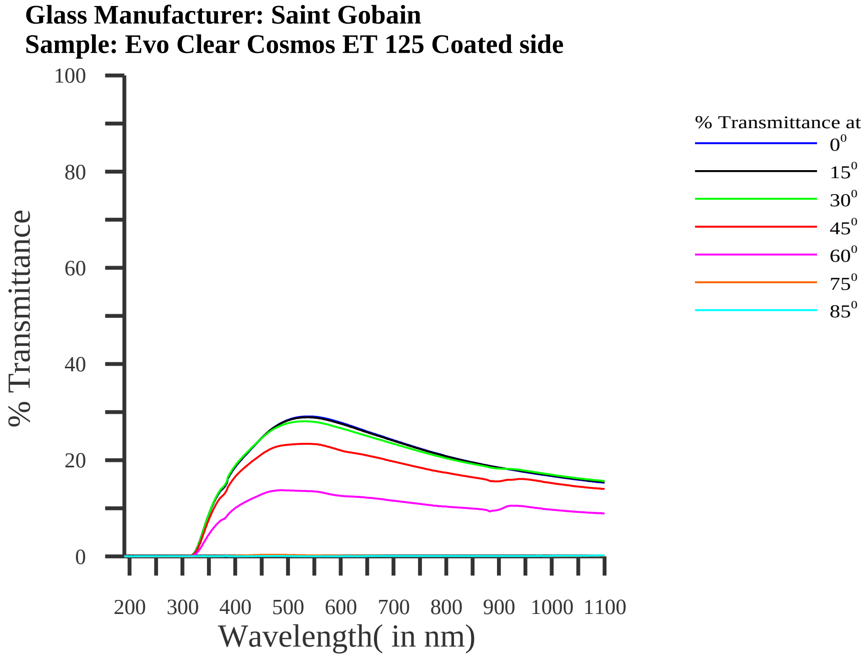


Fig 4.23: % Transmittance vs Wavelength for coated side of sample ET 125

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 550 nm and

then decreases at a slower rate with increase in wavelength as shown in Fig 4.22 and 4.23. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region. The transmittance of Fig.4.22 and Fig.4.23 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incidence angles varying from 0^0 - 85^0.

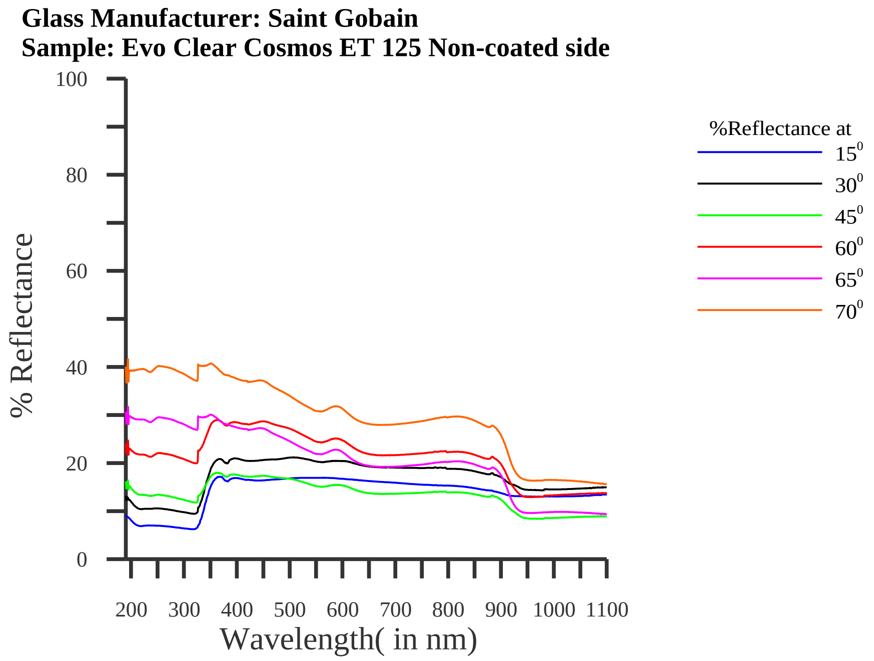
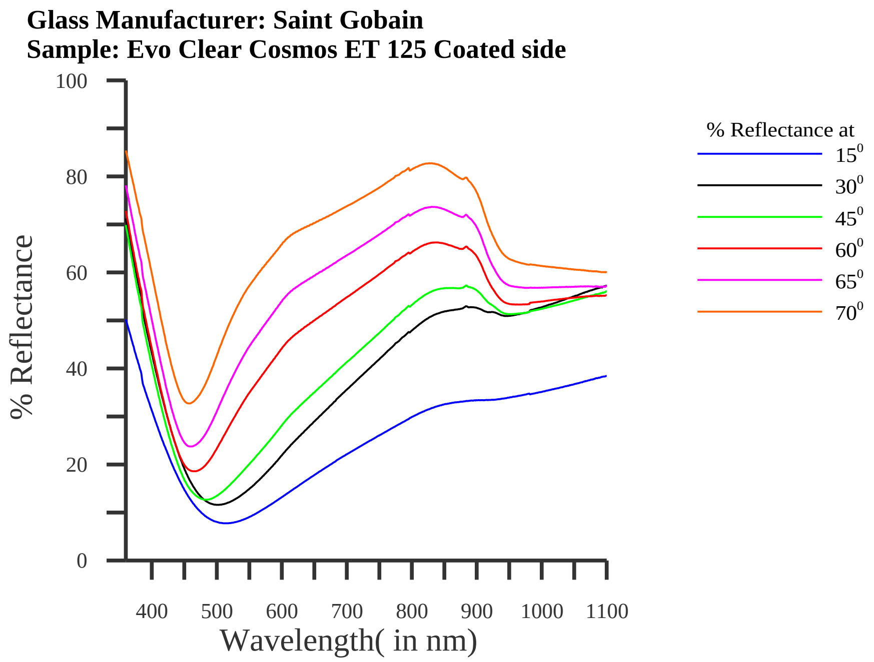


Fig 4.24: % Reflectance vs Wavelength for non-coated side of sample ET 125

The reflectance is increased with the increase of incidence angle except for 45^0 and 65^0 as seen in Fig 4.24. The coating on the other side of the sample could be the reason for this exception. The nature of the curve shows a sharp increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.24.

The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region. The reflectance of Fig. 4.24 is measured by Perkin-Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.



. Fig 4.25: % Reflectance vs Wavelength for coated side of sample ET 125

From Fig. 4.25 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve shows sharp decrease for shorter wavelength and then gradually increases till 850 nm and then gradually decreases. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and high reflectance at shorter wavelength because of coating. The reflectance of above figure is measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

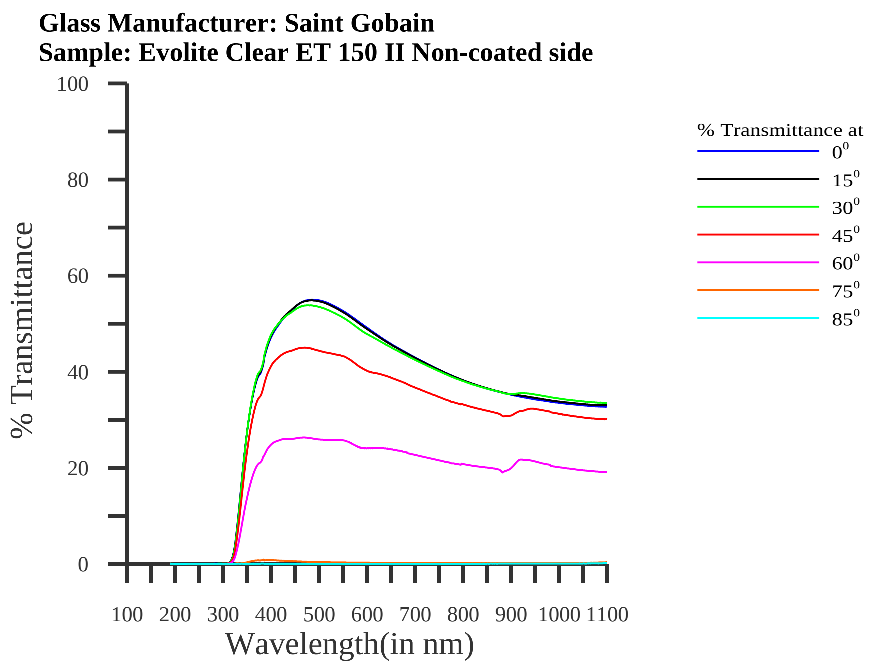


Fig 4.26: % Transmittance vs Wavelength for non-coated side of sample ET 150-II

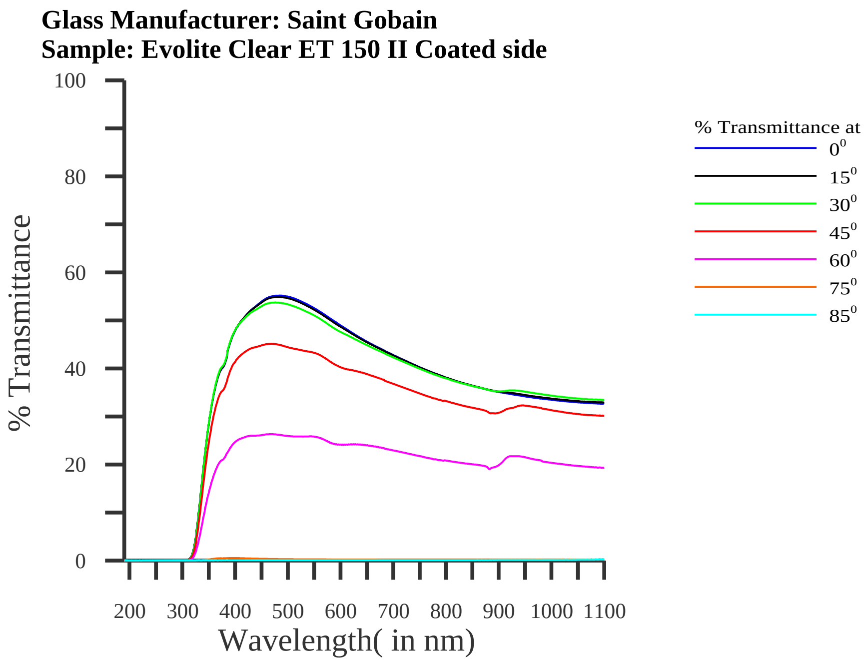


Fig 4.27: % Transmittance vs Wavelength for coated side of sample ET 150-II

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 500 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.26 and 4.27. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region. The transmittance of Fig.4.26 and Fig.4.27 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incidence angles varying from 0^0 - 85^0.

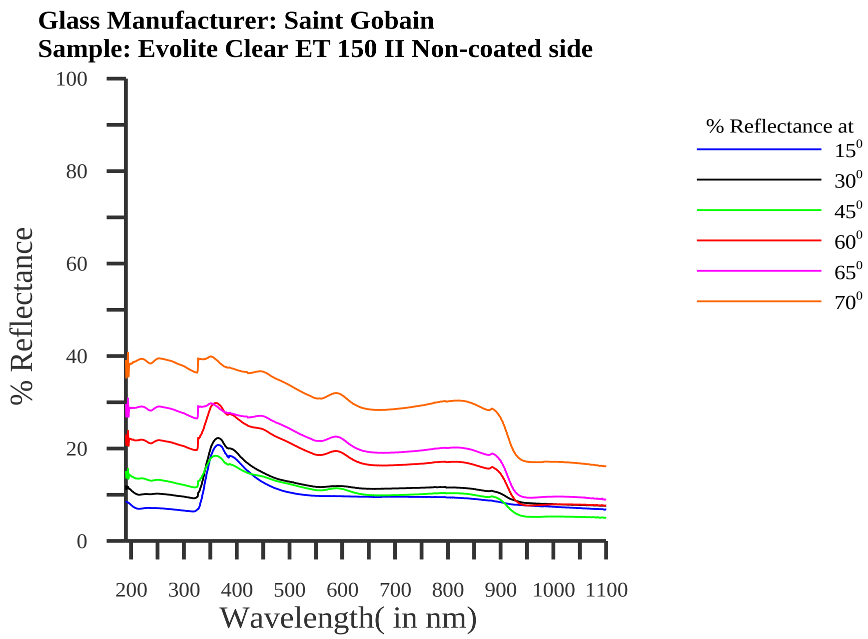


Fig 4.28: % Reflectance vs Wavelength for non-coated side of sample ET 150 II

The reflectance is increased with the increase of incidence angle except for 45^0 as seen in Fig 4.28. The coating on the other side of the sample could be the reason for this exception. The nature of the curve shows a sharp increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.28. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region. The reflectance of Fig. 4.28 is measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

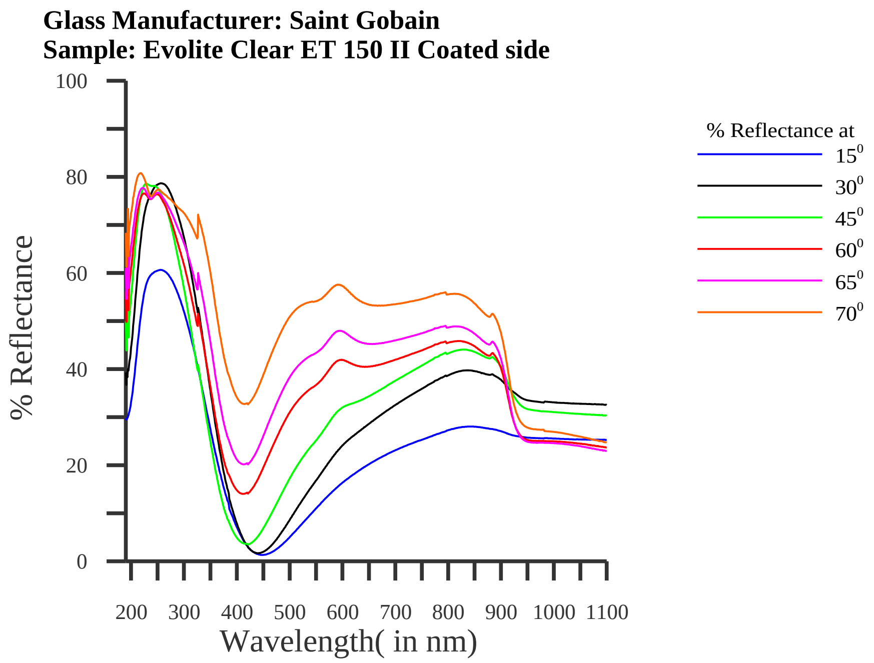


Fig 4.29: % Reflectance vs Wavelength for coated side of sample ET 150 II

From Fig. 4.29 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve is such that the curves first sharply increase up to 300 nm and then sharply decreases up to 450 nm and again gradually increases till 850 nm and then gradually decreases.

The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and high reflectance at shorter wavelength is because of coating.

The reflectance of above figure is measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV-vis range at incidence angles varying from 15^0 - 70^0.

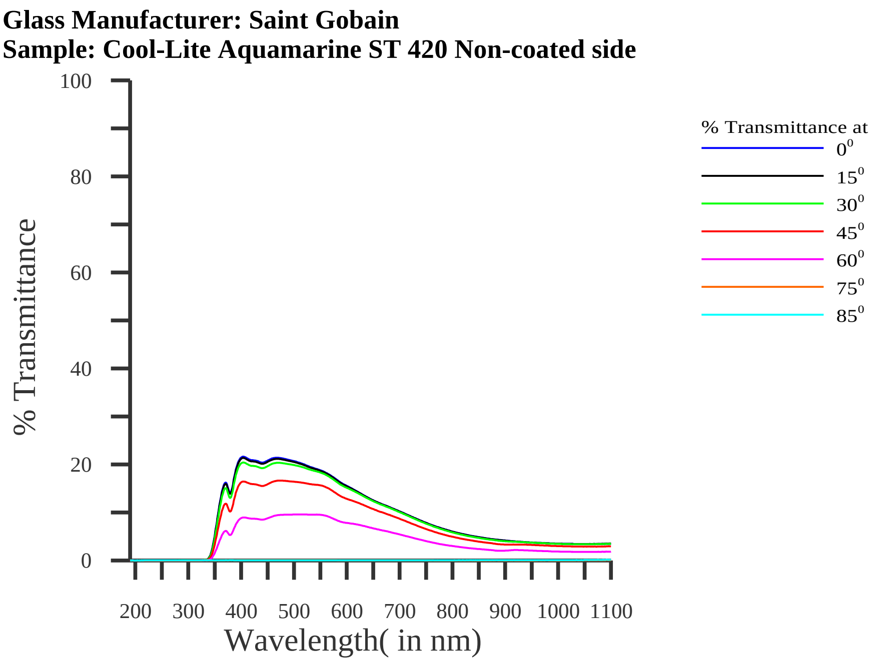


Fig 4.30: % Transmittance vs Wavelength for non-coated side of sample ST 420

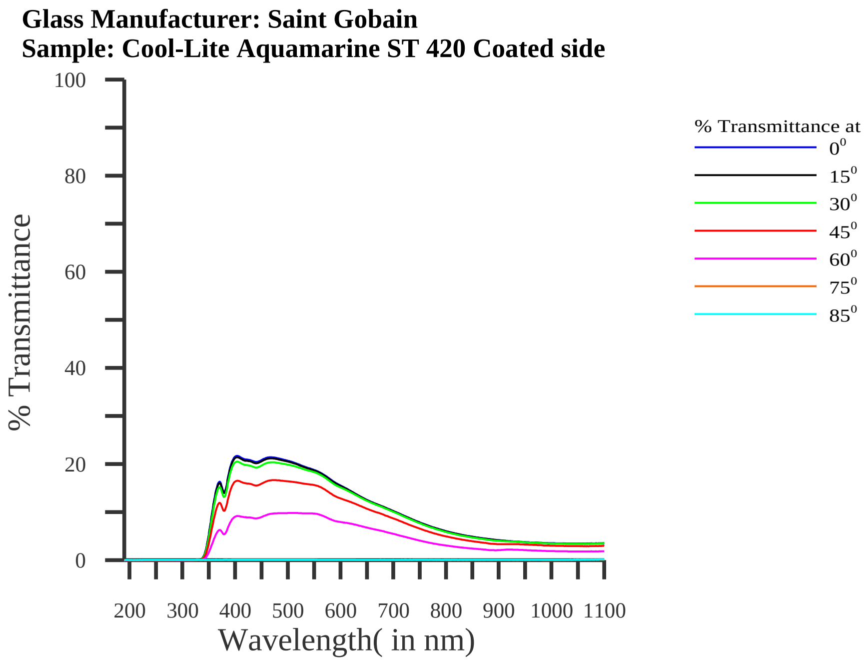


Fig 4.31: % Transmittance vs Wavelength for coated side of sample ST 420

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 400 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.30 and Fig4.31. The transmittance of Fig.4.30 and Fig.4.31 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incidence angles varying from 0^0 - 85^0. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

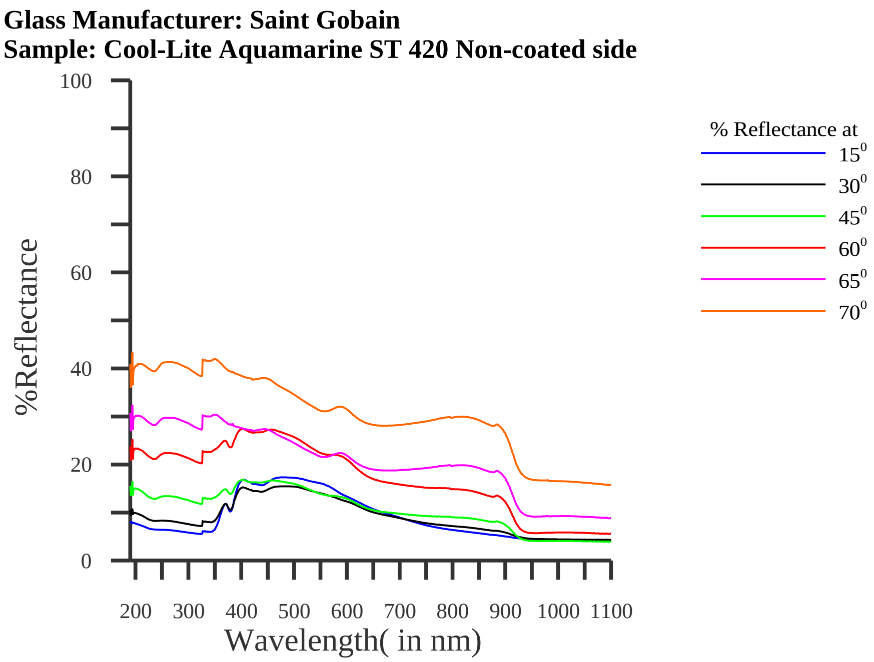


Fig 4.32: % Reflectance vs Wavelength for non-coated side of sample ST 420

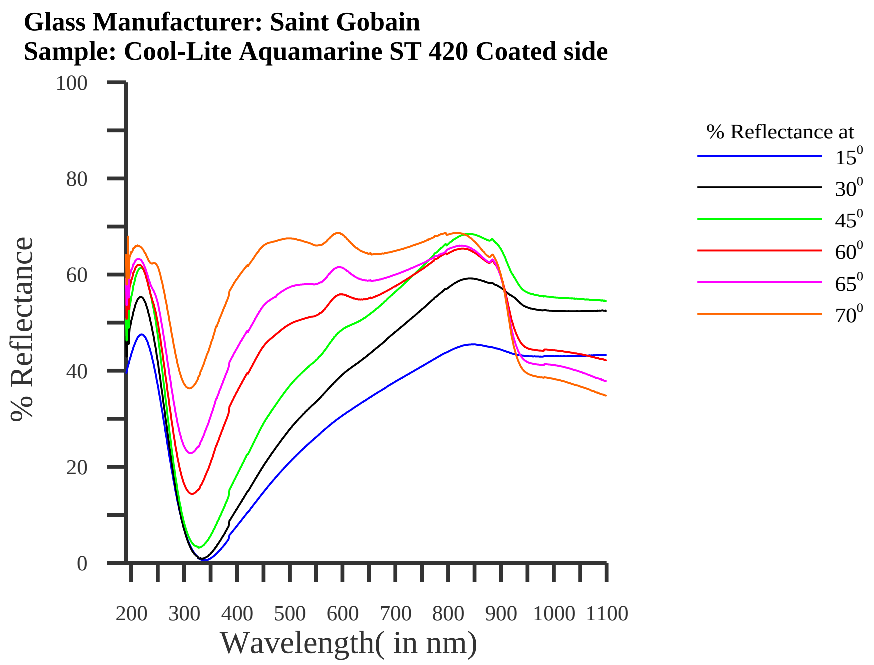


Fig 4.33: % Reflectance vs Wavelength for coated side of sample ST 420

The reflectance is about same for incidence angle 15^0 - 45^0 for visible range and then increases with increase in incidence angle as seen in Fig 4.32. The nature of the curve shows a sharp increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.32.

From Fig. 4.33 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve shows small rise then sharp decrease for shorter wavelength and then gradually increases till 850 nm and then gradually decreases. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and high reflectance at shorter wavelength because of coating on this side of glazing sample. The reflectance of Fig. 4.32 and Fig.4.33 are measured by Perkin- Elmer Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

Glass Manufacturer: Saint Gobain
Sample: Cool-Lite Turquiose ST 436 Non-coated side

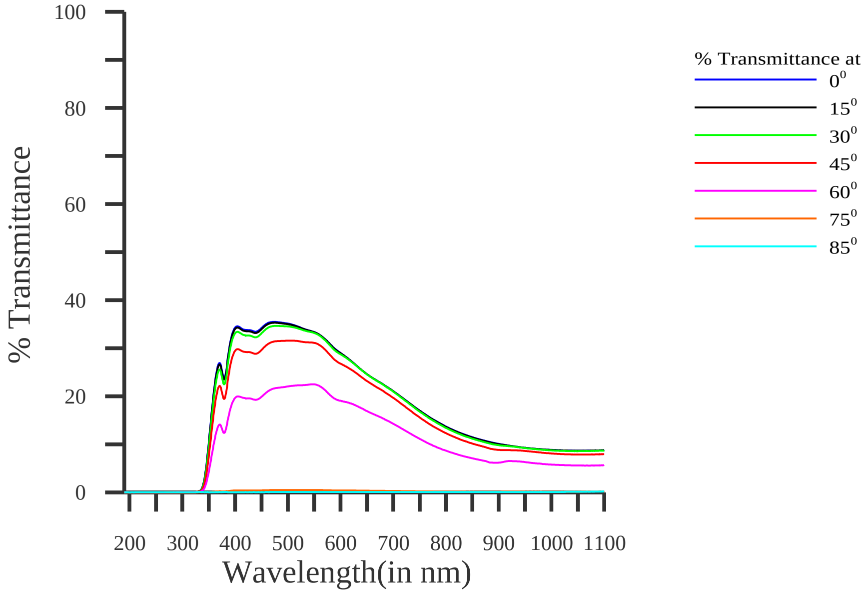


Fig 4.34: % Transmittance vs Wavelength for non-coated side of sample ST 436

Glass Manufacturer: Saint Gobain
Sample: Cool-Lite Turquiose ST 436 Coated side

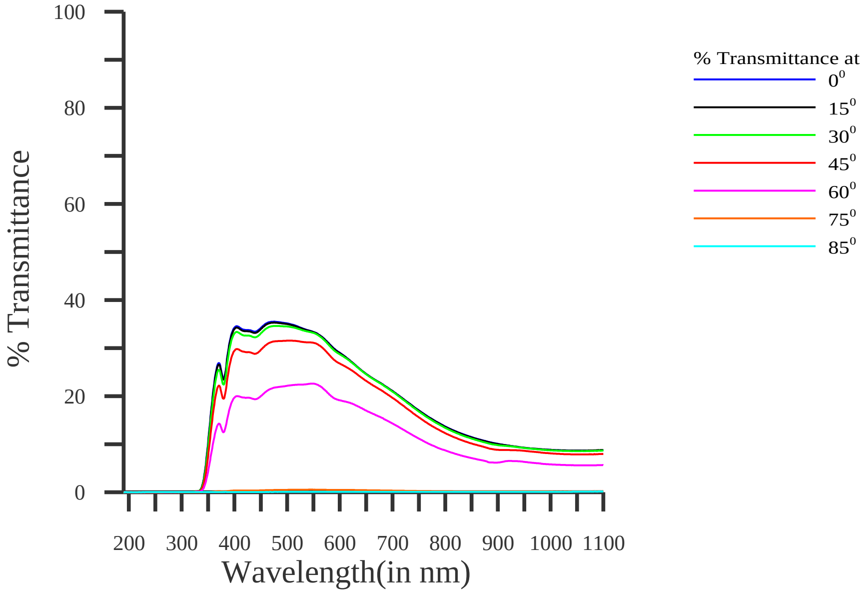


Fig 4.35: % Transmittance vs Wavelength for coated side of sample ST 436

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 400 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.34 and Fig 4.35. The transmittance of Fig 4.34 and Fig 4.35 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incidence angles varying from 0^0 - 85^0. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

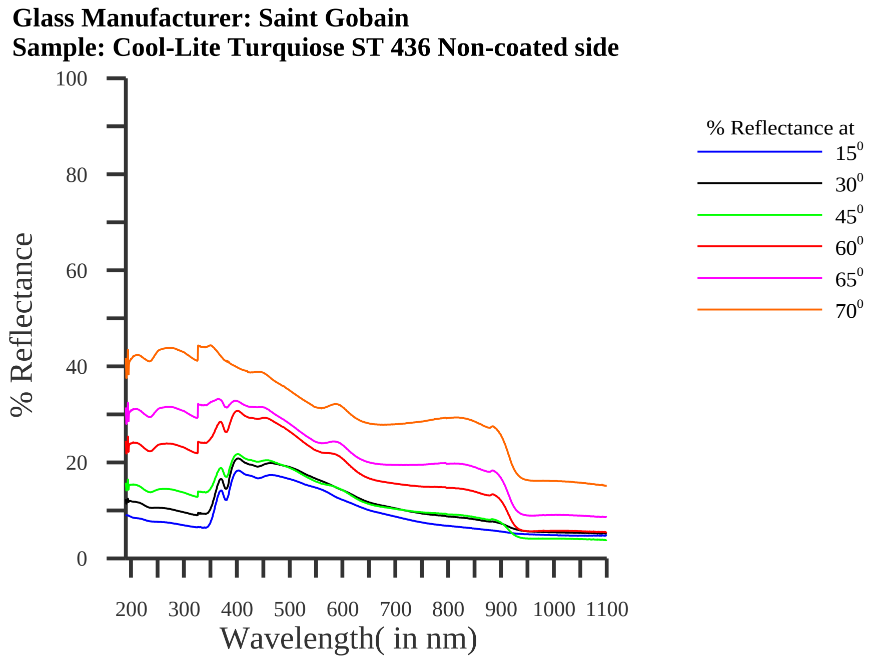


Fig 4.36: % Reflectance vs Wavelength for non-coated side of sample ST 436

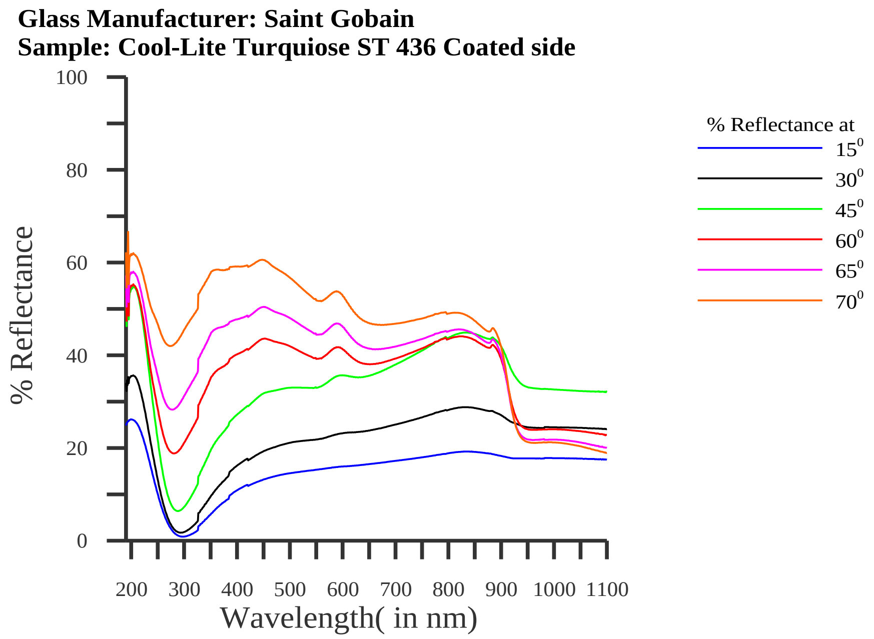


Fig 4.37: % Reflectance vs Wavelength for coated side of sample ST 436

From Fig. 4.36 we can see that reflectance increases with the increase of incidence angle. The nature of the curve shows a sharp increase for shorter wavelength and then decreases gradually with increase in wavelength. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

From Fig. 4.37 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve shows sharp decrease for shorter wavelength and then gradually increases till 850 nm and then gradually decreases. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and also because of coating on this surface of glazing sample.

The reflectance off Fig.4.36 and Fig 4.37 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

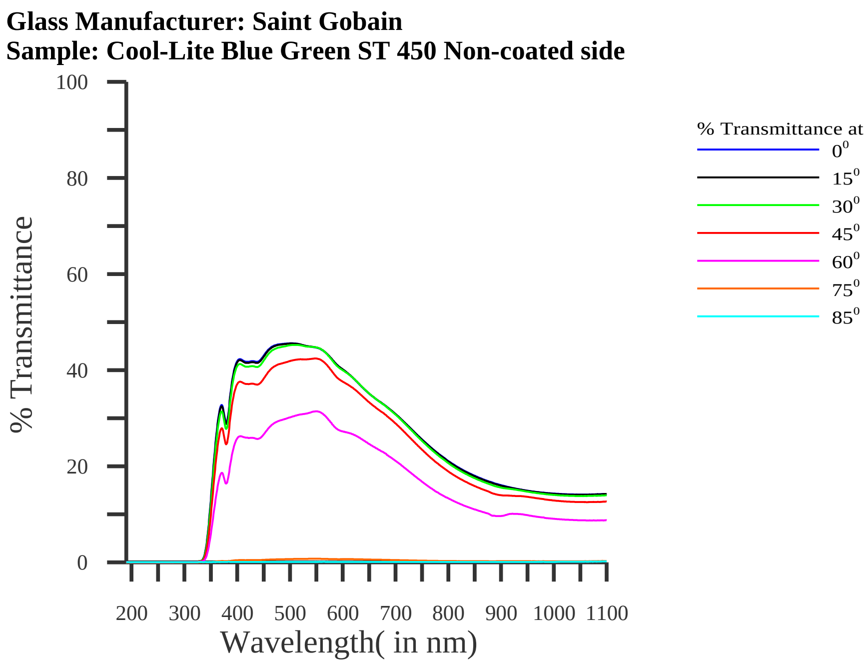


Fig 4.38: % Transmittance vs Wavelength for non-coated side of sample ST 450

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 500 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.38 and Fig 4.39 and transmittance are measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV-vis range at incidence angles varying from 0^0 - 85^0.

The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

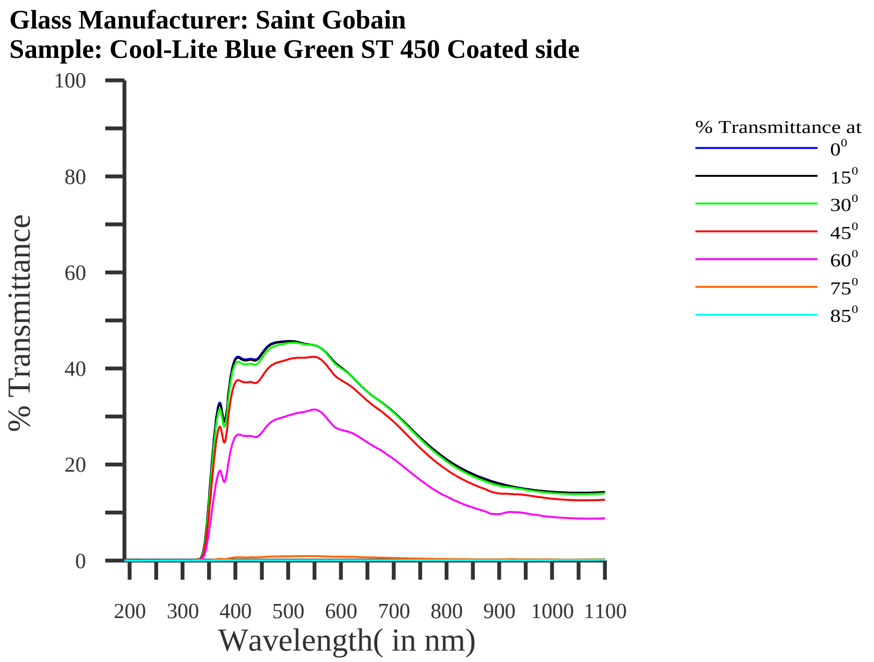


Fig 4.39: % Transmittance vs Wavelength for coated side of sample ST 450

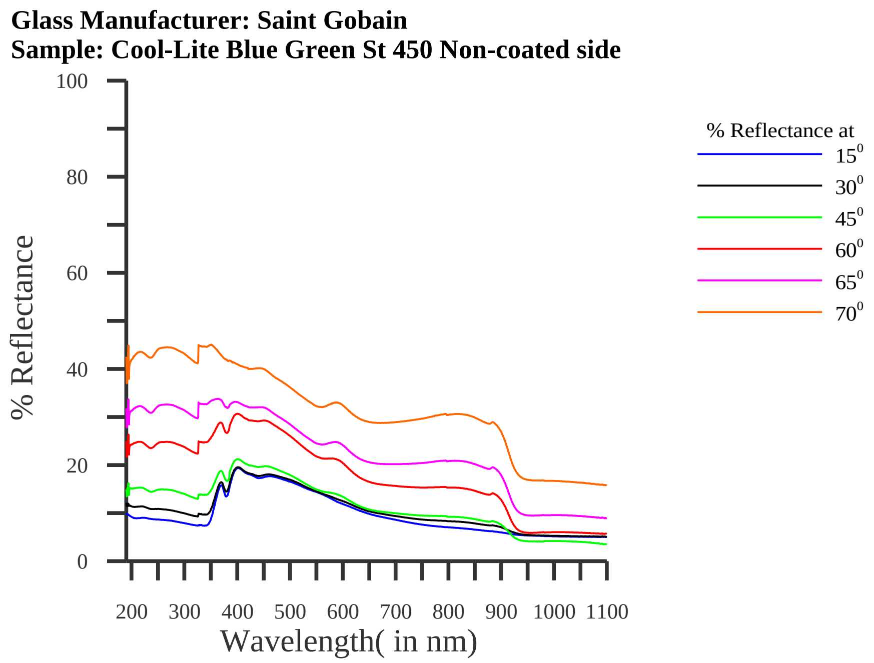


Fig 4.40: % Reflectance vs Wavelength for non-coated side of sample ST 450

The reflectance is about same for incidence angle 15^0 - 45^0 for visible range and then reflectance increases with the increase of incidence angle as seen in Fig 4.40. The nature of the curve shows increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.40. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region.

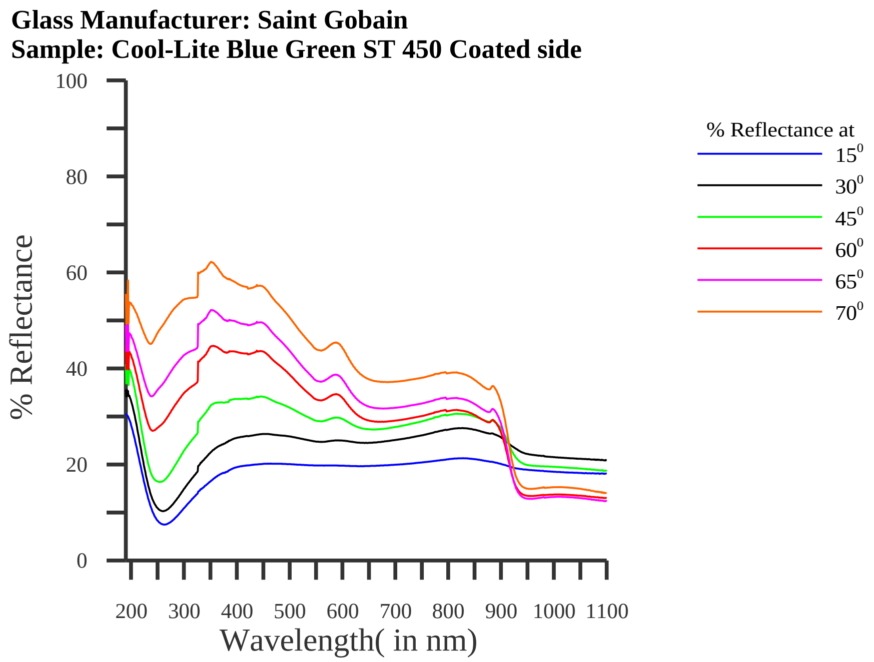


Fig 4.41: % Reflectance vs Wavelength for coated side of sample ST 450

From Fig. 4.41 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve shows sharp decrease for shorter wavelength and then sharply increases till 400 nm and then gradually decreases. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and also because of coating on this surface of glazing sample. The reflectance of Fig.4.40 and Fig. 4.41 are measured by Perkin-Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

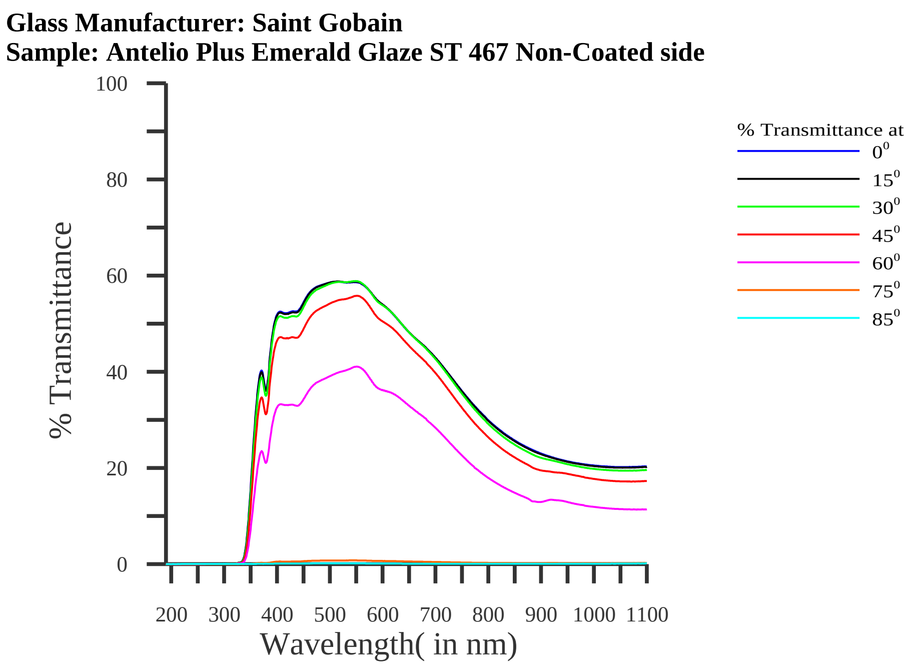


Fig 4.42: % Transmittance vs Wavelength for non-coated side of sample ST 467

Glass Manufacturer: Saint Gobain
Sample: Antelio Plus Emerald Glaze ST 467 Coated side

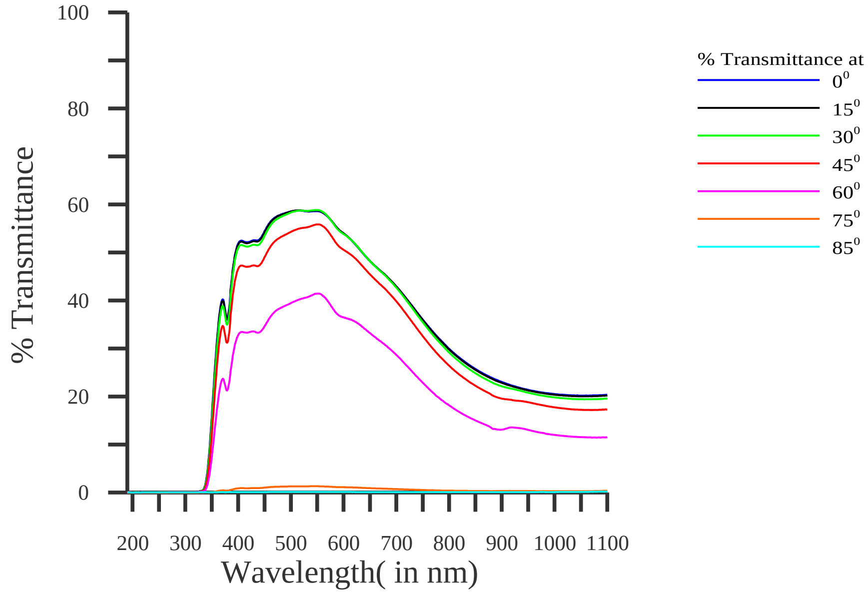


Fig 4.43: % Transmittance vs Wavelength for coated side of sample ST 467

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 500 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.42 and 4.43 and the transmittance of Fig.4.42 and Fig.4.43 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incidence angles varying from 0^0 - 85^0. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

Glass Manufacturer: Saint Gobain
Sample: Antelio Plus Emerald Glaze ST 467 Non-Coated side

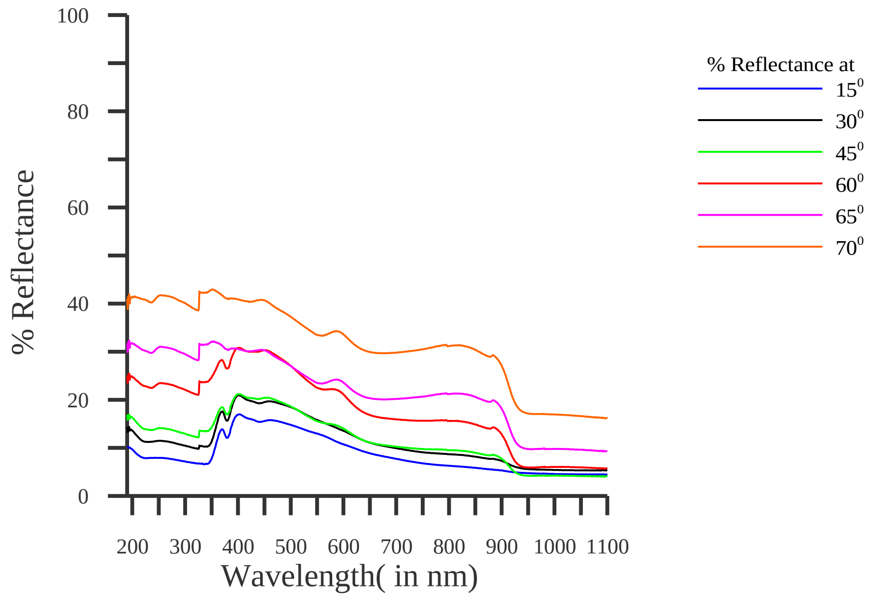


Fig 4.44: % Reflectance vs Wavelength for non-coated side of sample ST 467

Glass Manufacturer: Saint Gobain
Sample: Antelio Plus Emerald Glaze ST 467 Coated side

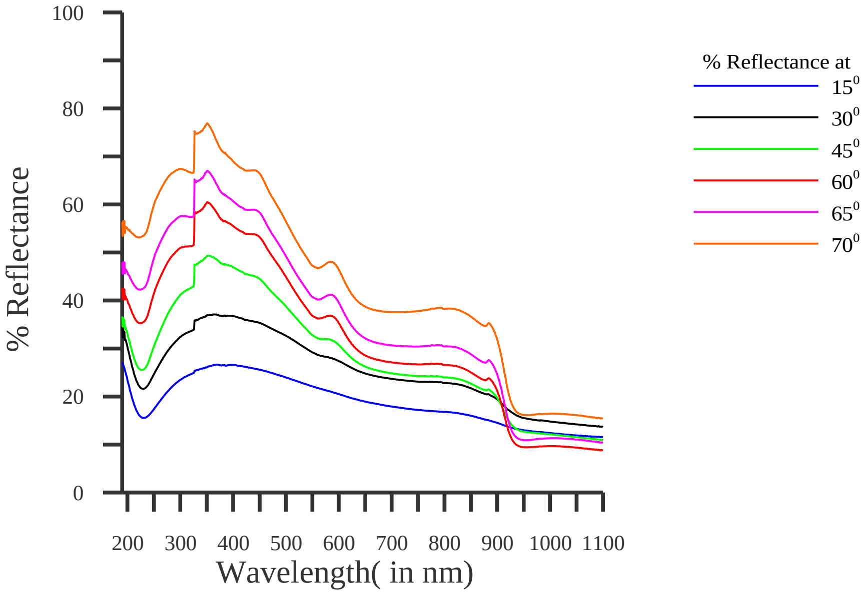


Fig 4.45: % Reflectance vs Wavelength for coated side of sample ST 467

The reflectance increases with the increase of incidence angle as seen in Fig 4.44. The nature of the curve shows a sharp increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.44. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region.

The reflectance is increased with the increase of incidence angle in Fig 4.45. The nature of curve shows sharp decrease for shorter wavelength and then sharply increases till 400 nm and then gradually decreases as wavelength increases.

The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and also because of coating on this surface of glazing sample.

The reflectance of Fig.4.44 and 4.45 is measured by Perkin- Elmer Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

Glass Manufacturer: Saint Gobain
Sample: Cool-Lite Tranquil Blue ST 720 Non-coated side

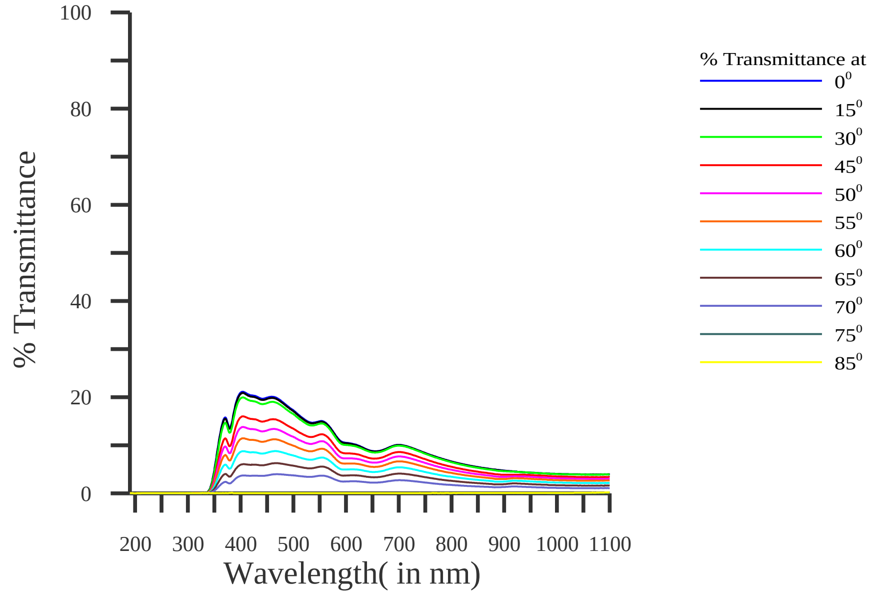


Fig 4.46: % Transmittance vs Wavelength for non-coated side of sample ST 720

Glass Manufacturer: Saint Gobain
Sample: Cool-Lite Tranquil Blue ST 720 Coated side

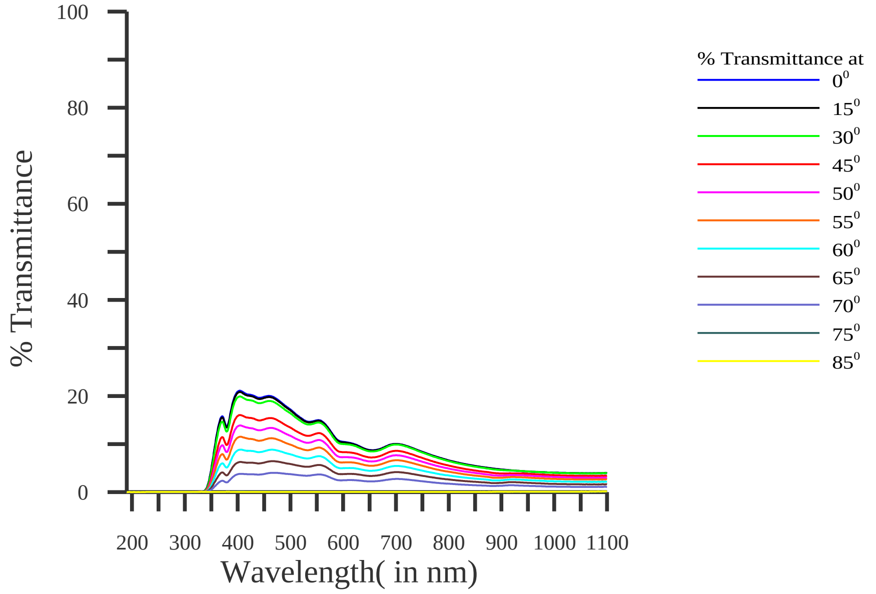


Fig 4.47: % Transmittance vs Wavelength for coated side of sample ST 720

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 400 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.46 and Fig4.47. The transmittance of Fig.4.46 and Fig.4.46 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incidence angles varying from 0^0 - 85^0. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

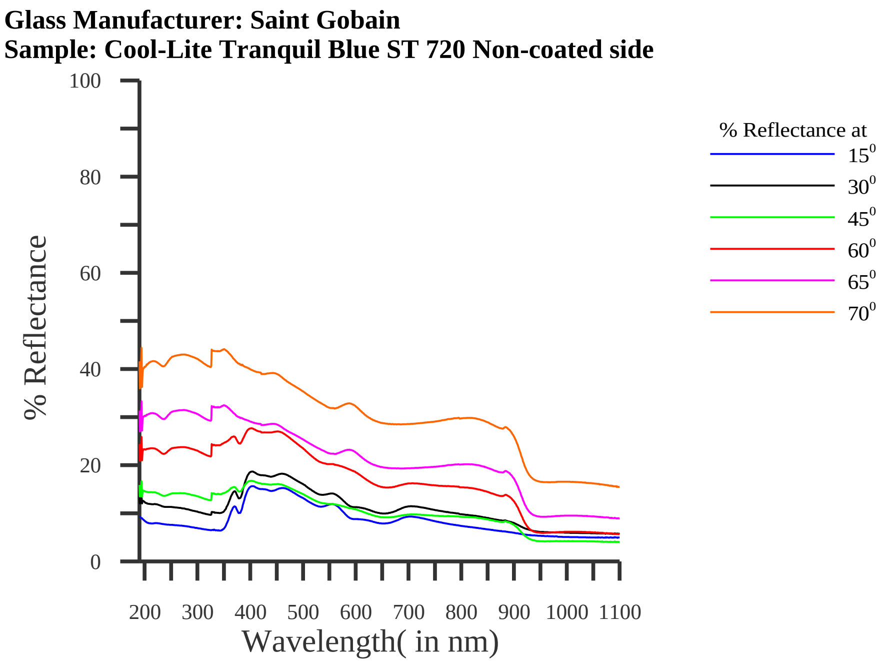


Fig 4.48: % Reflectance vs Wavelength for non-coated side of sample ST 720

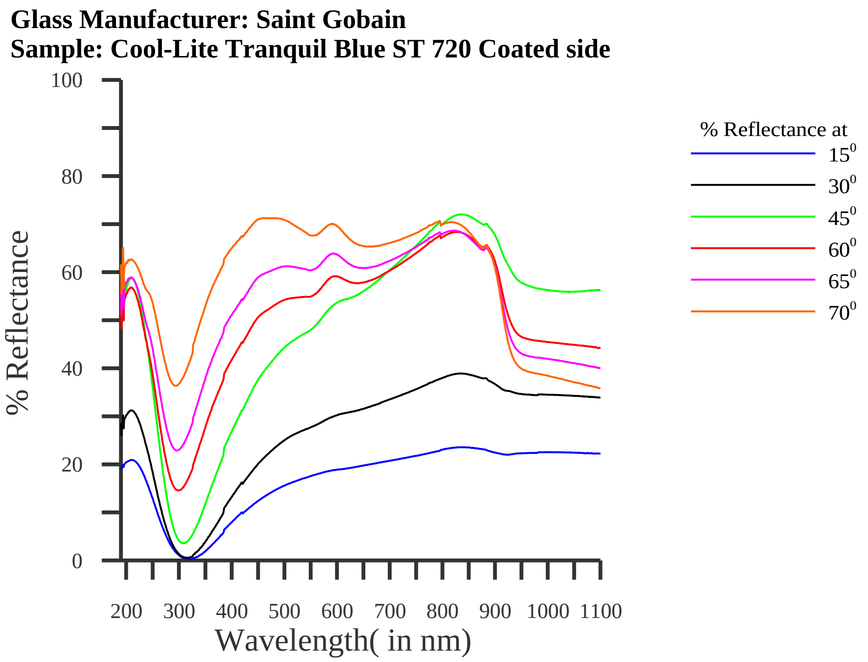


Fig 4.49: % Reflectance vs Wavelength for coated side of sample ST 720

The reflectance increases with increase in incidence angle except for 45^0 as seen in Fig 4.48. The coating on the other side of the sample could be the reason for this exception. The nature of the curve shows a sharp increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.48.

From Fig. 4.49 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve shows small rise then sharp decrease for shorter wavelength and then gradually increases till 850 nm and then gradually decreases. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and high reflectance at shorter wavelength because of coating on this side of glazing sample. The reflectance of Fig. 4.48 and Fig.4.49 are measured by Perkin- Elmer Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

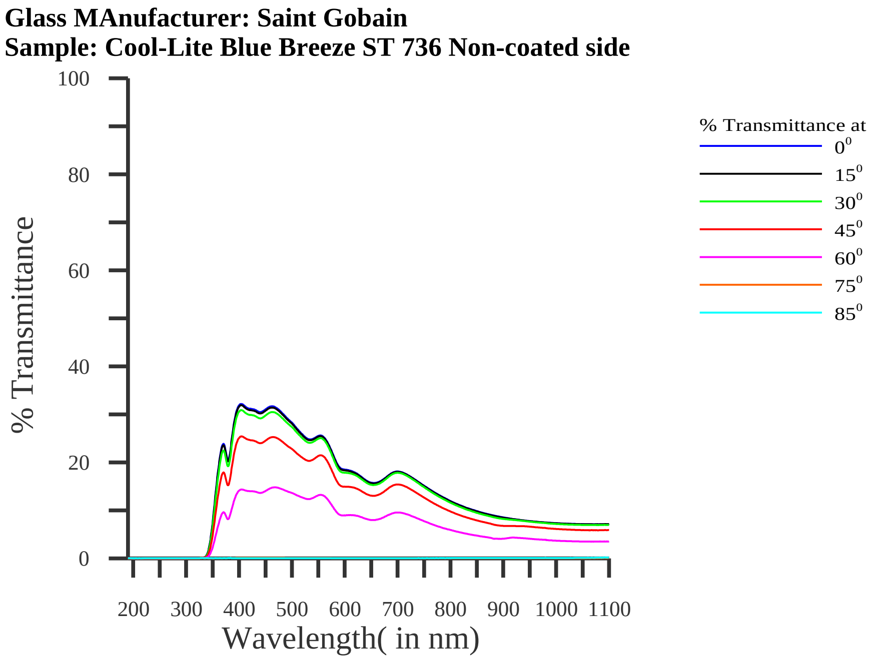


Fig 4.50: % Transmittance vs Wavelength for non-coated side of sample ST 736

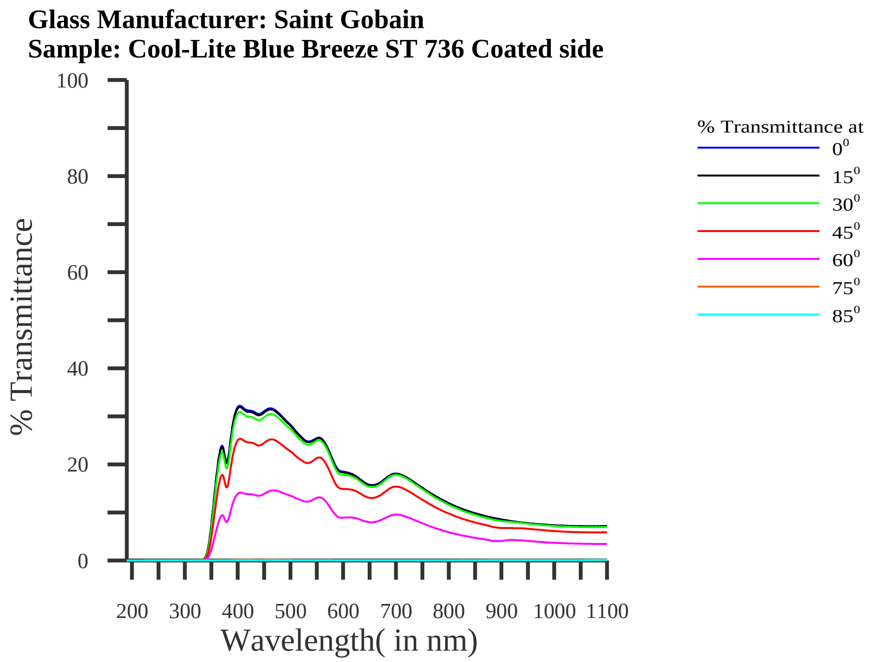


Fig 4.51: % Transmittance vs Wavelength for coated side of sample ST 736

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 400 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.50 and Fig 4.51. The transmittance of Fig 4.50 and Fig 4.51 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incidence angles varying from 0^0 - 85^0. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

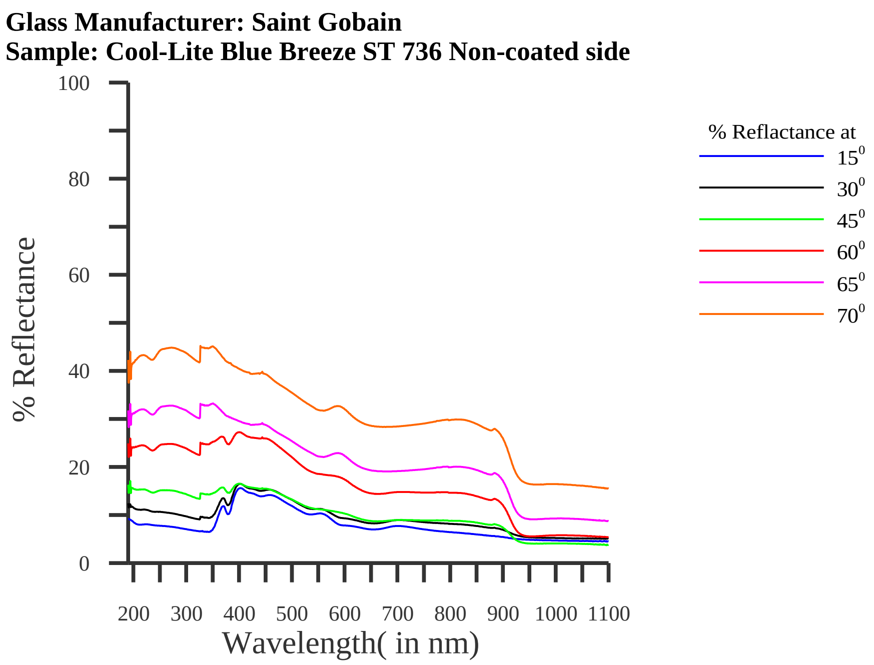


Fig 4.52: % Reflectance vs Wavelength for non-coated side of sample ST 736

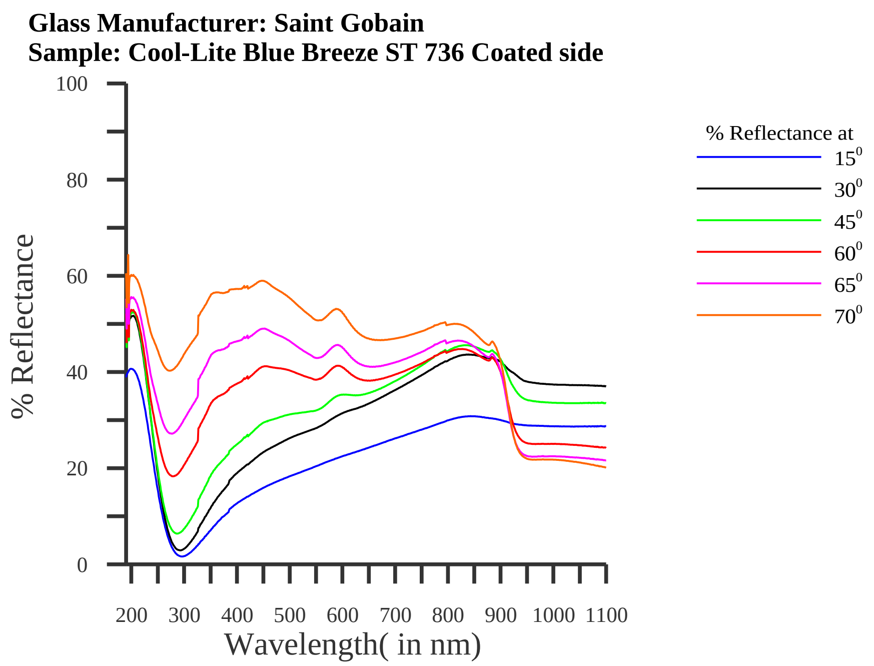


Fig 4.53: % Reflectance vs Wavelength for coated side of sample ST 736

From Fig. 4.52 we can see that reflectance increases with the increase of incidence angle. The nature of the curve shows increase for shorter wavelength and then decreases gradually with increase in wavelength. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

From Fig. 4.53 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve shows sharp decrease for shorter wavelength and then gradually increases till 850 nm and then gradually decreases. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and also because of coating on this surface of glazing sample.

The reflectance off Fig.4.52 and Fig 4.53 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

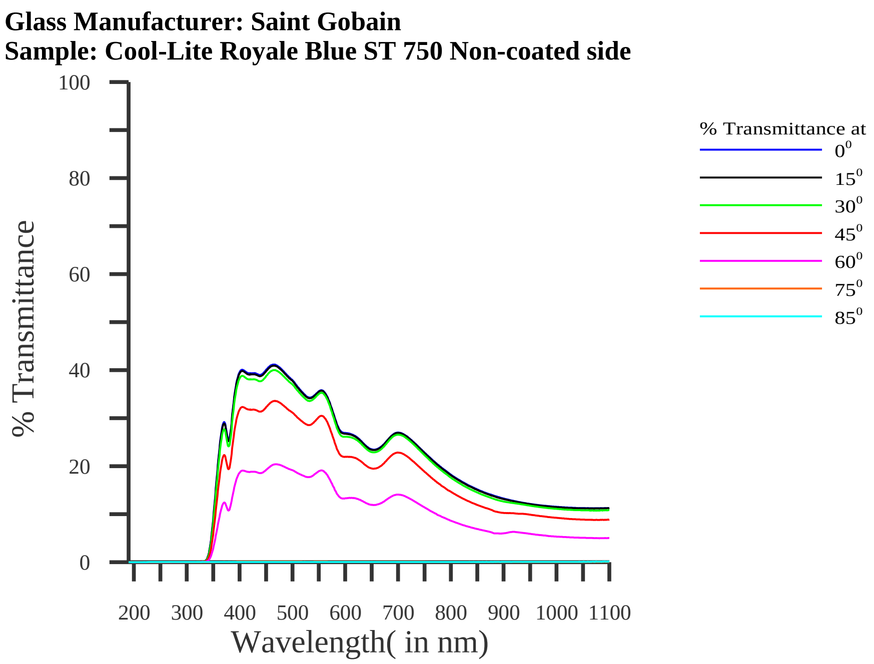


Fig 4.54: % Transmittance vs Wavelength for non-coated side of sample ST 750

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 400 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.54 and Fig 4.55 and transmittance are measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV-vis range at incidence angles varying from 0^0 - 85^0.

The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

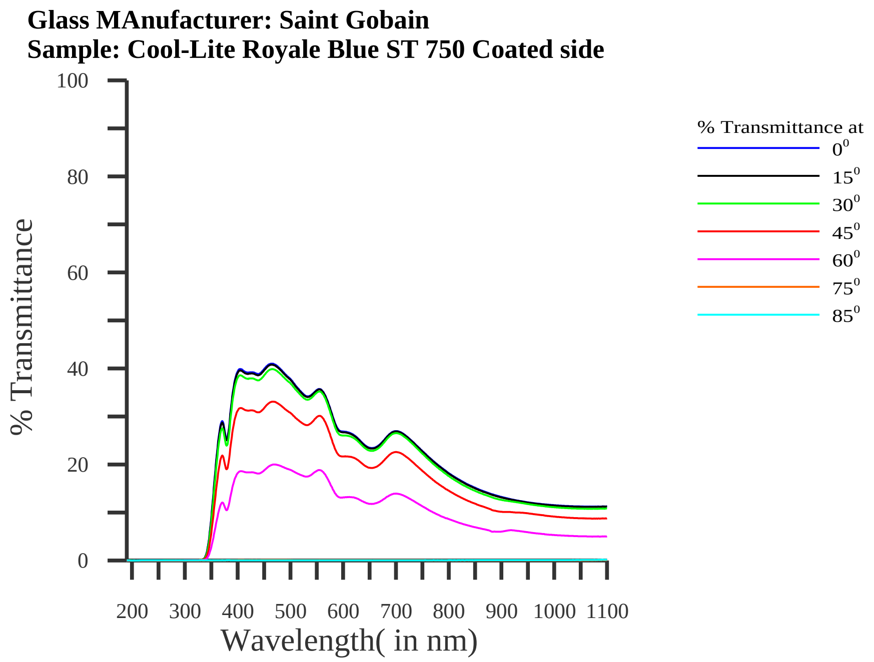


Fig 4.55: % Transmittance vs Wavelength for coated side of sample ST 750

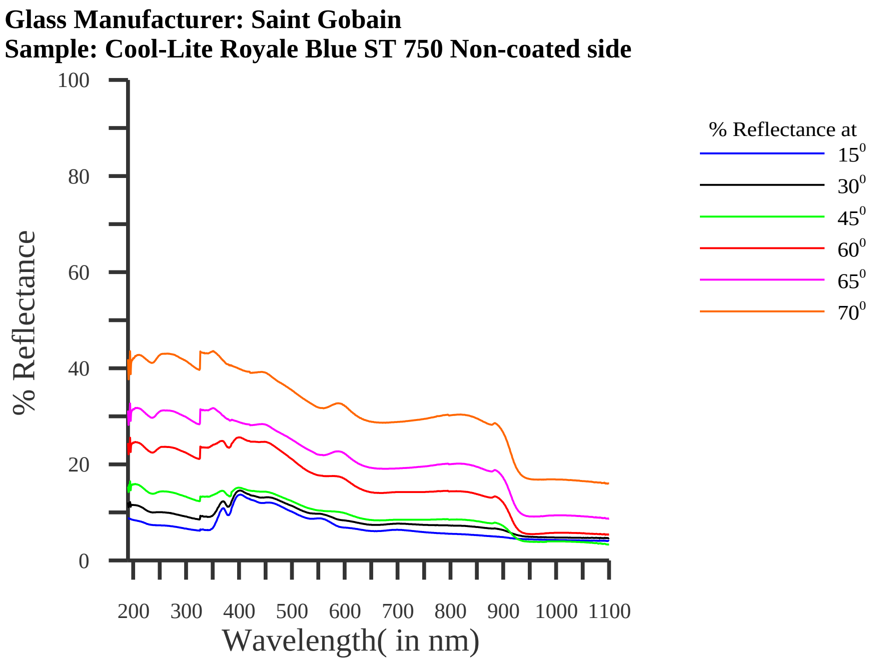


Fig 4.56: % Reflectance vs Wavelength for non-coated side of sample ST 750

The reflectance is increased with the increase of incidence angle as seen in Fig 4.56. The nature of the curve shows a sharp increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.56.

The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region.

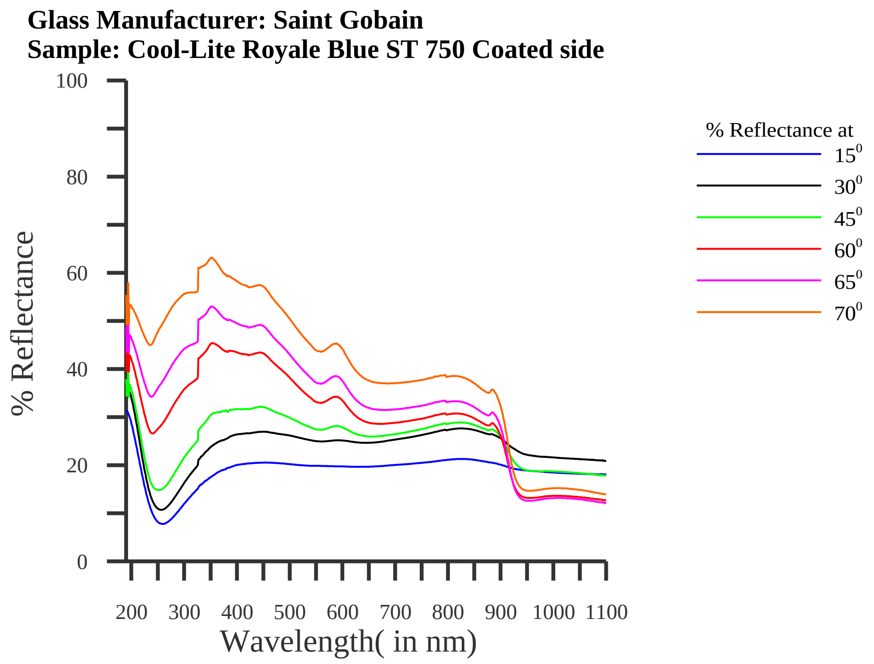


Fig 4.57: % Reflectance vs Wavelength for coated side of sample ST 750

From Fig. 4.57 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve shows sharp decrease for shorter wavelength and then sharply increases till 400 nm and then gradually decreases. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and also because of coating on this surface of glazing sample. The reflectance of Fig.4.56 and Fig. 4.57 are measured by Perkin-Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

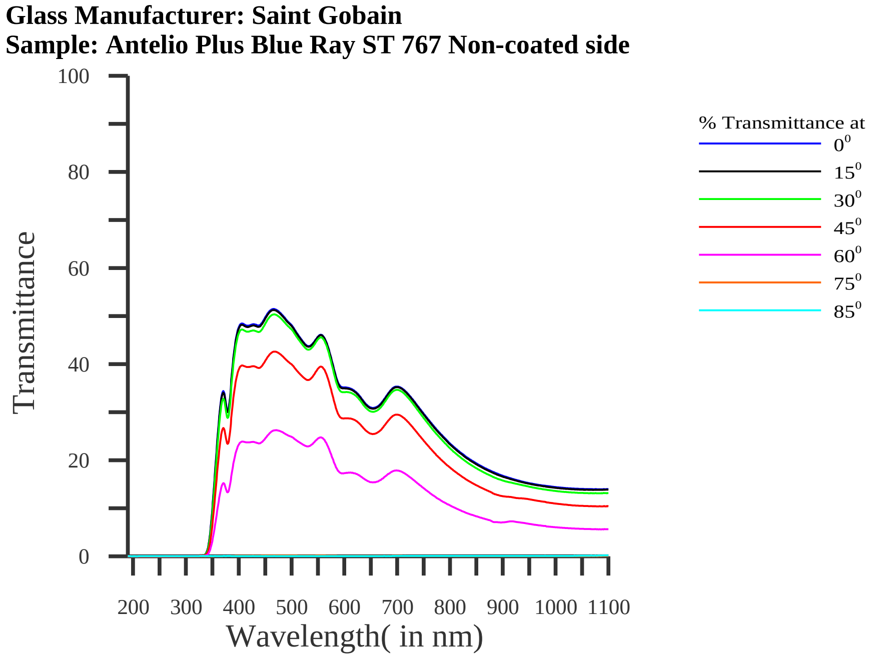


Fig 4.58: % Transmittance vs Wavelength for non-coated side of sample ST 767

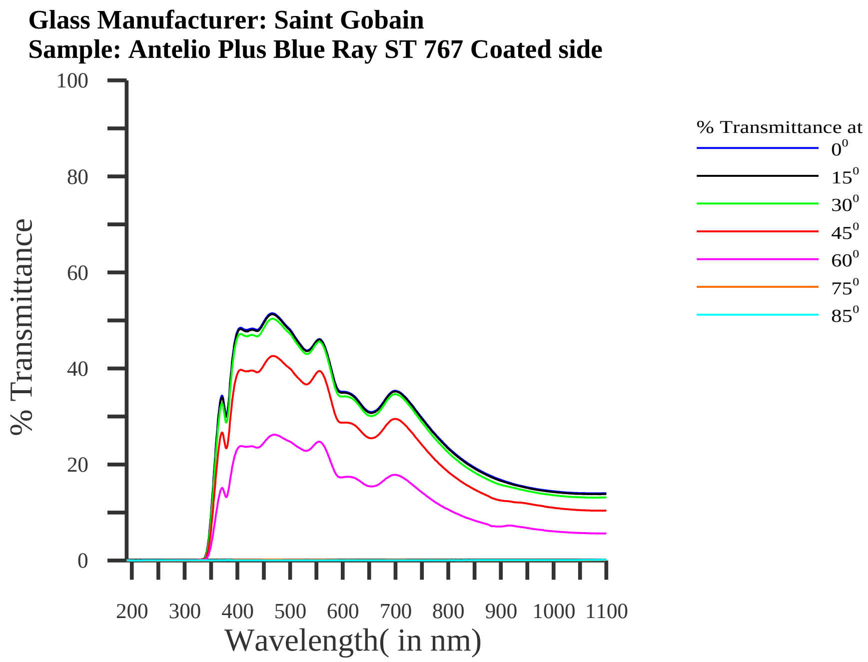


Fig 4.59: % Transmittance vs Wavelength for coated side of sample ST 767

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 470 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.58 and Fig 4.59 and transmittance are measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV-vis range at incidence angles varying from 0^0 - 85^0. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

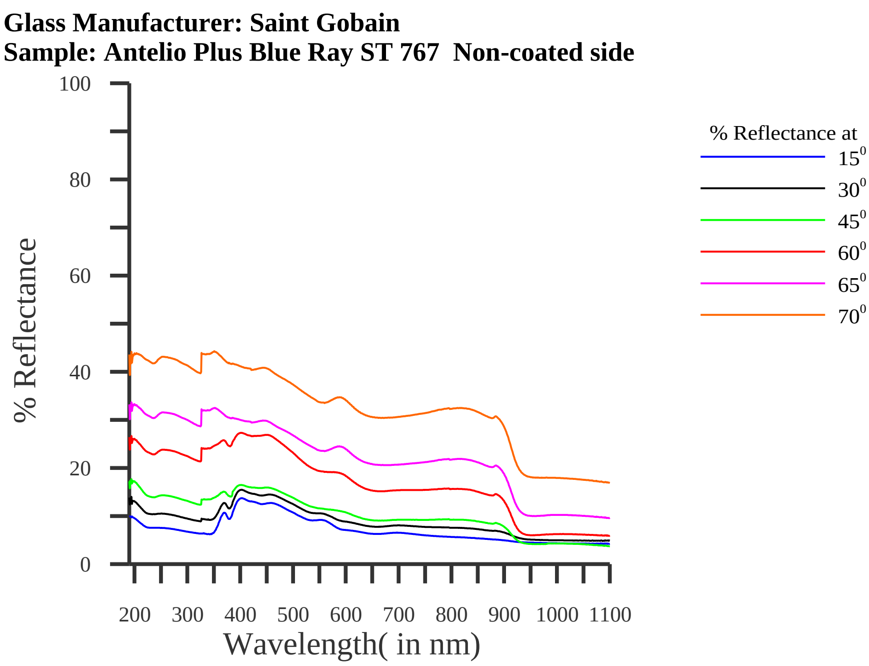


Fig 4.60: % Reflectance vs Wavelength for non-coated side of sample ST 767

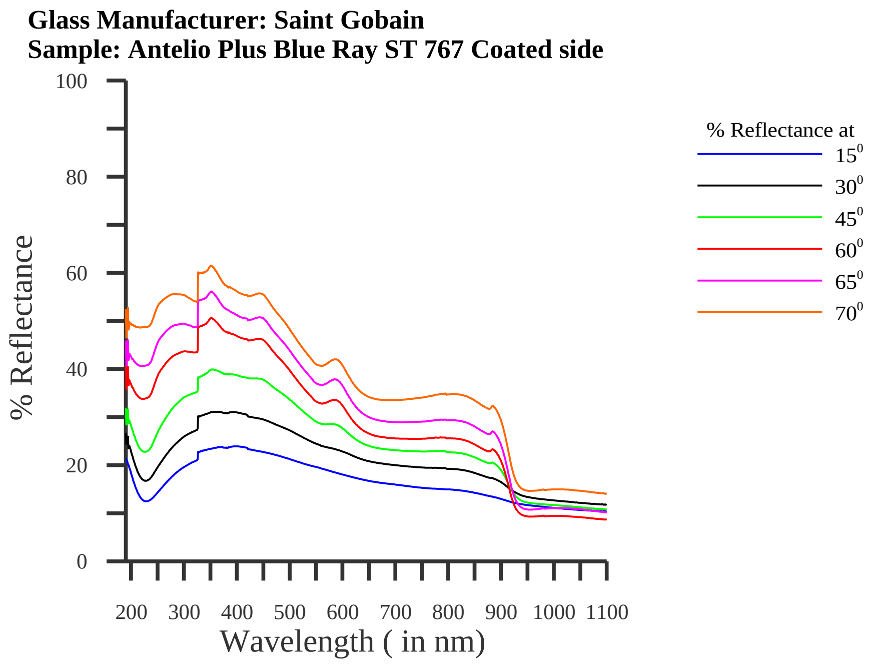


Fig 4.61: % Reflectance vs Wavelength for coated side of sample ST 767

The reflectance increases with the increase of incidence angle as seen in Fig 4.60. The nature of the curve shows increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.60. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region.

The reflectance is increased with the increase of incidence angle in Fig 4.61. The nature of curve shows sharp decrease for shorter wavelength and then sharply increases till 400 nm and then gradually decreases as wavelength increases.

The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and also because of coating on this surface of glazing sample.

The reflectance of Fig.4.60 and 4.61 is measured by Perkin- Elmer Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

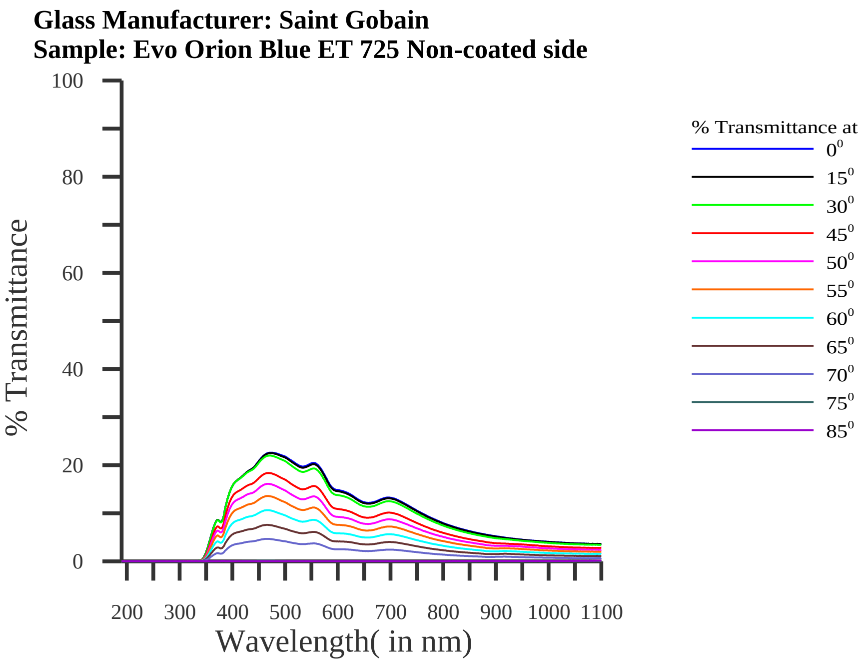


Fig 4.62: % Transmittance vs Wavelength for non-coated side of sample ET 725

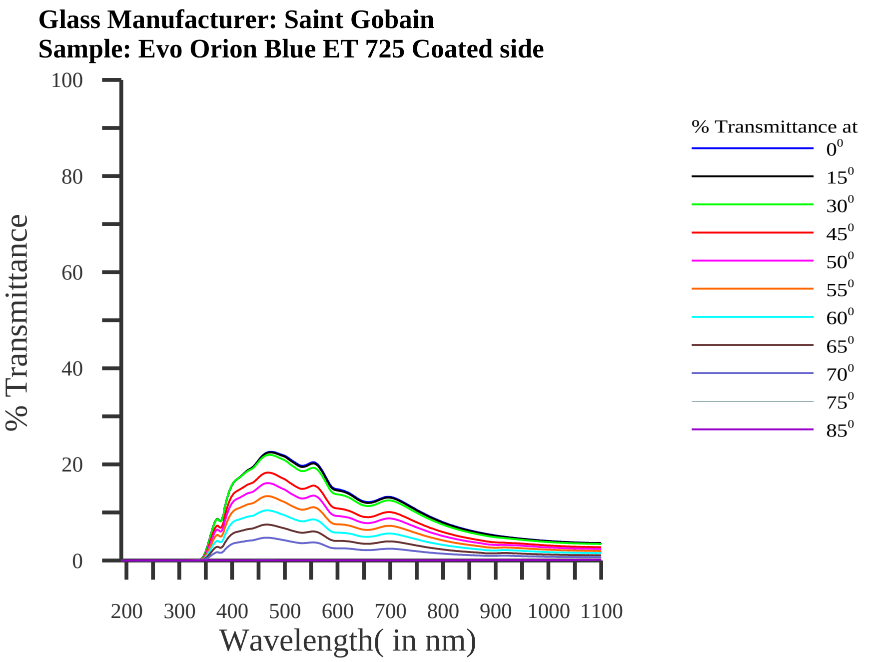


Fig 4.63: % Transmittance vs Wavelength for coated side of sample ET 725

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 470 nm and then decreases at a slower rate with increase in wavelength as shown in Fig 4.62 and 4.63. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region. The transmittance of Fig.4.62 and Fig.4.63 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incidence angles varying from 0^0 - 85^0.

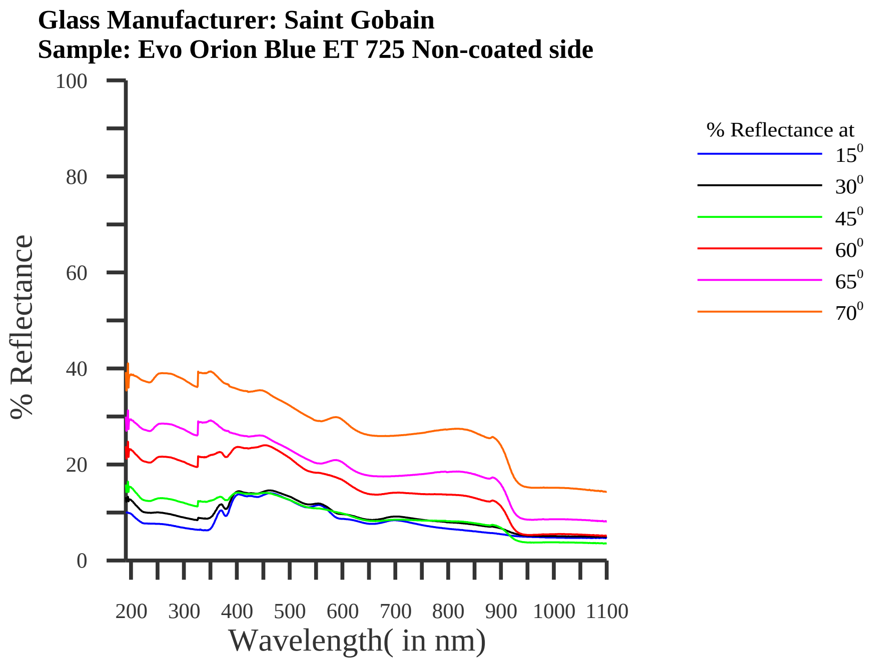


Fig 4.64: % Reflectance vs Wavelength for non-coated side of sample ET 725

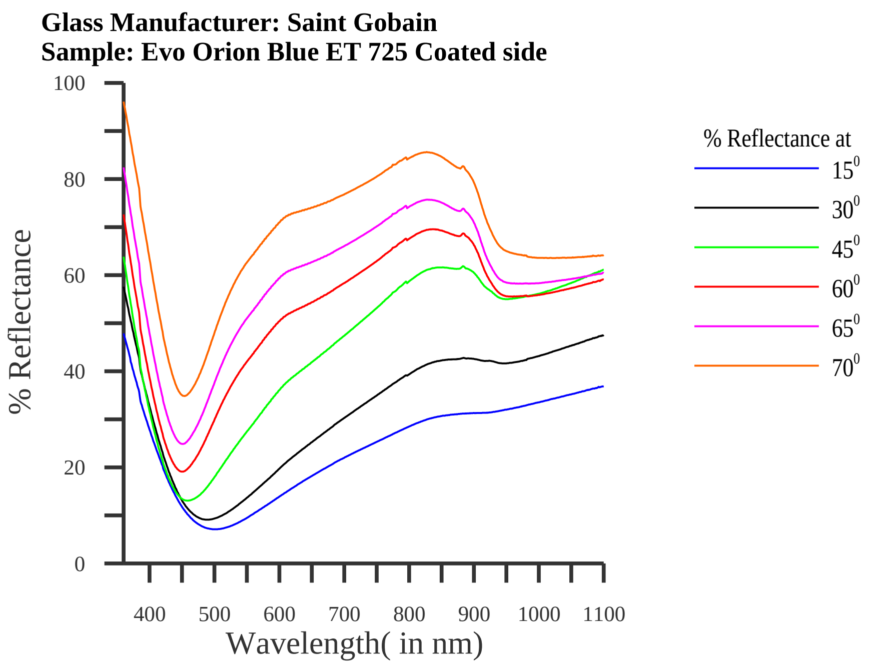


Fig 4.65: % Reflectance vs Wavelength for coated side of sample ET 725

The reflectance is nearly same for $15^0 – 45^0$ in visible range and increases with the increase of incidence angle seen in Fig 4.64.The nature of the curve shows an increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.64. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region.

From Fig. 4.65 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve shows sharp decrease for shorter wavelength and then gradually increases till 850 nm and then gradually decreases. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and high reflectance at shorter wavelength because of coating. The reflectance of Fig 6.64 and 6.65 are measured by Perkin-Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

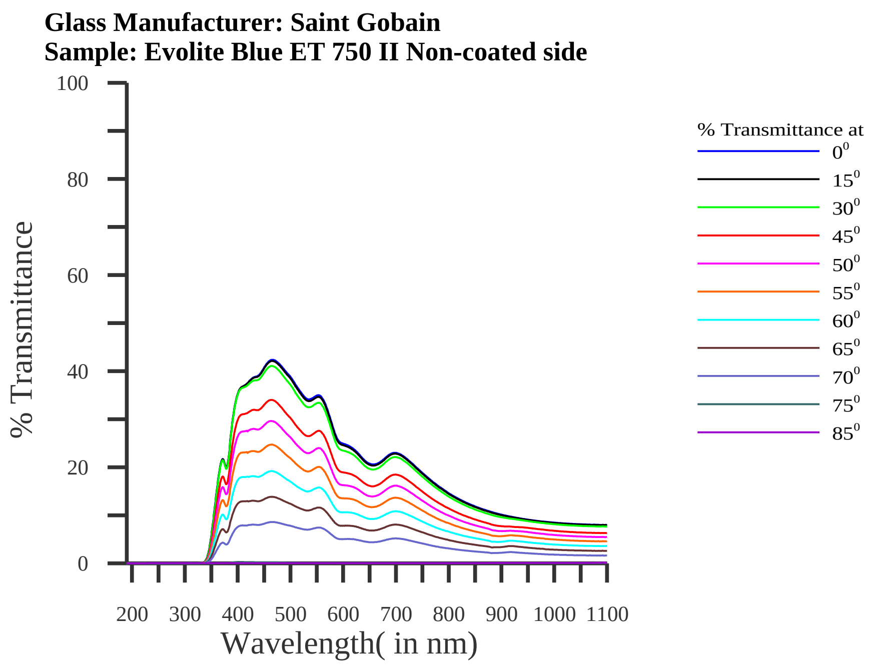


Fig 4.66: % Transmittance vs Wavelength for non-coated side of sample ET 750 II

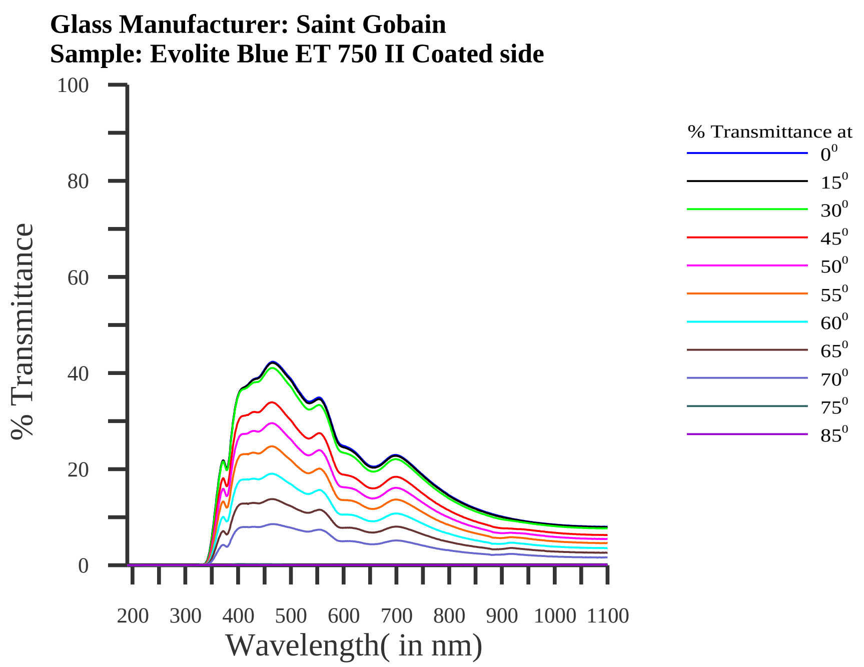


Fig 4.67: % Transmittance vs Wavelength for coated side of sample ET 750 II

The transmittance remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and the nature of the curve shows a sharp increase up to 500 nm and

then decreases at a slower rate with increase in wavelength as shown in Fig 4.66 and 4.67. The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for long wave radiations, i.e. in the infrared region.

The transmittance of Fig.4.66 and Fig.4.67 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in visible and near infrared wavelength at incidence angles varying from 0^0 - 85^0.

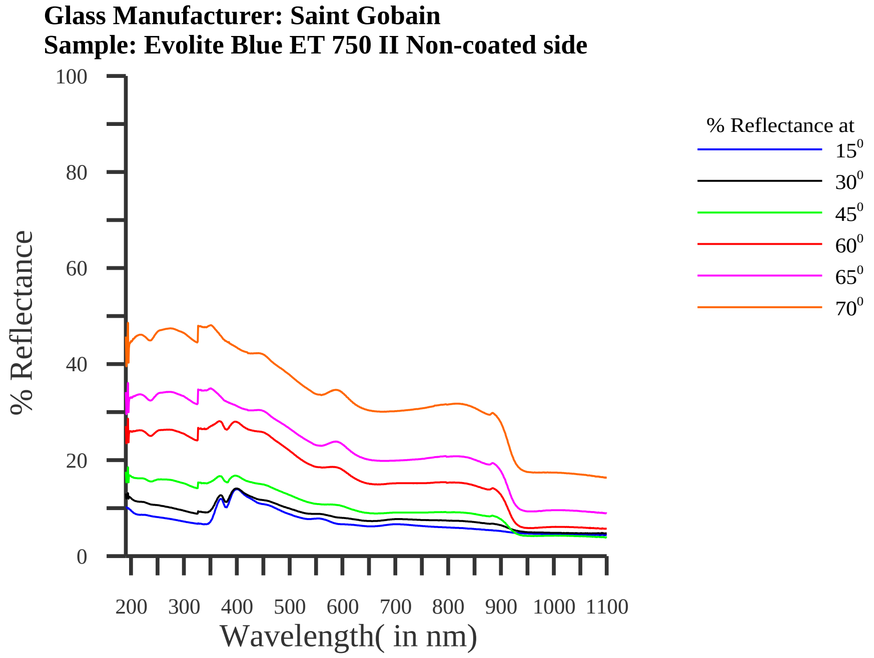


Fig 4.68: % Reflectance vs Wavelength for non-coated side of sample ET 750 II

The reflectance is increased with the increase of incidence angle as seen in Fig 4.68. The nature of the curve shows increase for shorter wavelength and then decreases gradually with increase in wavelength in Fig 4.68.

The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region.

The reflectance of Fig. 4.68 is measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

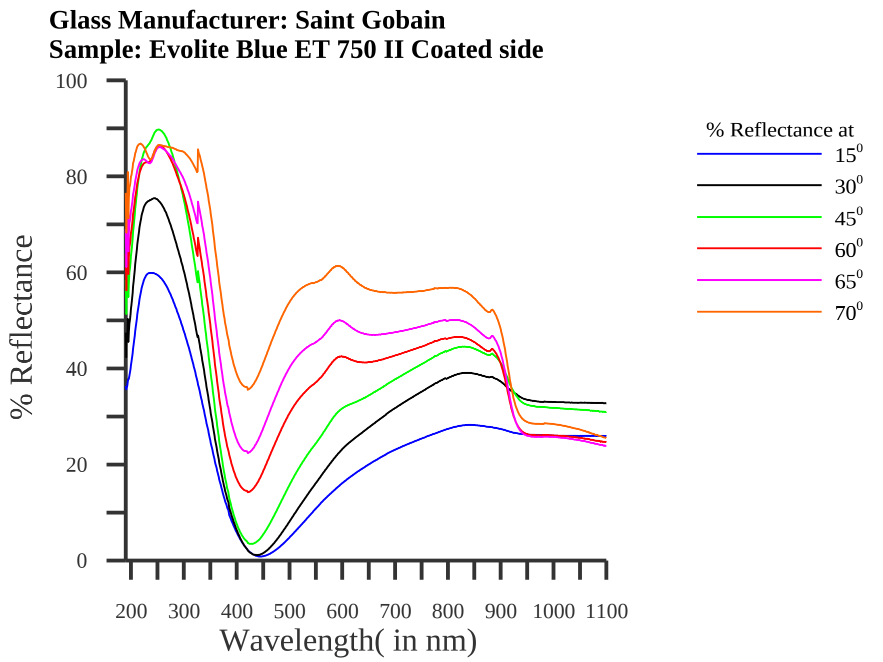


Fig 4.69: % Reflectance vs Wavelength for coated side of sample ET 750 II

From Fig. 4.69 we can say that the reflectance is increased with the increase of incidence angle. The nature of curve is such that the curves first sharply increase up to 250 nm and then sharply decreases up to 450 nm and again gradually increases till 850 nm and then gradually decreases.

The reason for such nature of this optical property of glazing is due to the fact that the glazing material is found to be opaque for infrared region and high reflectance at shorter wavelength is because of coating.

The reflectance of Fig.4.68 and Fig.4.69 are measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range at incidence angles varying from 15^0 - 70^0.

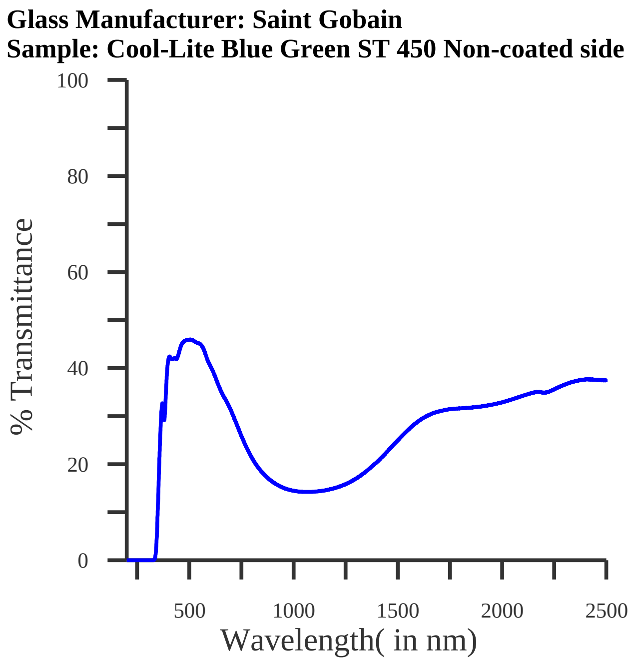


Fig 4.70: % Transmittance vs Wavelength for non-coated side of sample ST 450

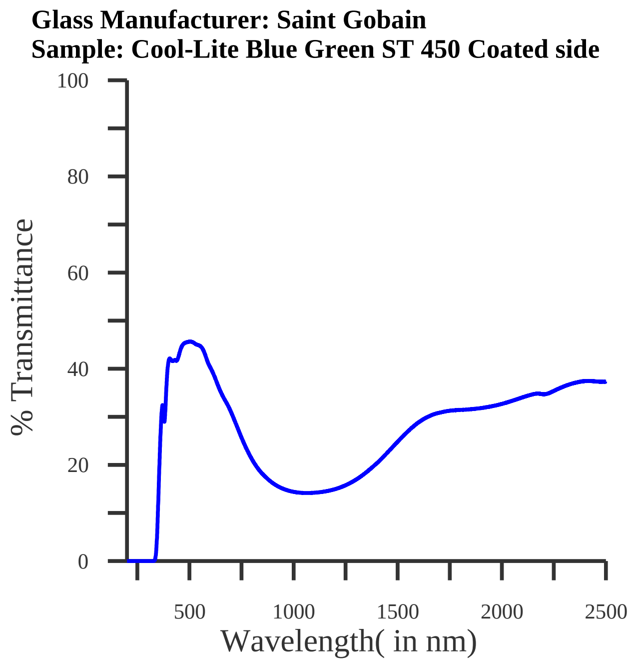


Fig 4.71: % Transmittance vs Wavelength for coated side of sample ST 450

From Fig.4.70 and 4.71 we can see that the nature of the curve shows a sharp increase up to 500 nm and then decreases at a slower rate till 1100 nm and then increases with increase in wavelength. The transmittance of Fig. 4.70 and Fig. 4.71 are measured by Jasco V-770 Spectrophotometer in UV- vis-Nir range for fixed incident angle. The transmittance characteristic of Fig. 4.70 and Fig.4.71 shows almost same characteristics as measured by Perkin-Elmer instrument while comparing these two figures with Fig. 4.38 and Fig. 4.39 in UV-vis range.

Glass Manufacturer: Saint Gobain
Sample: Cool-Lite Blue Green ST 450 Non-coated side

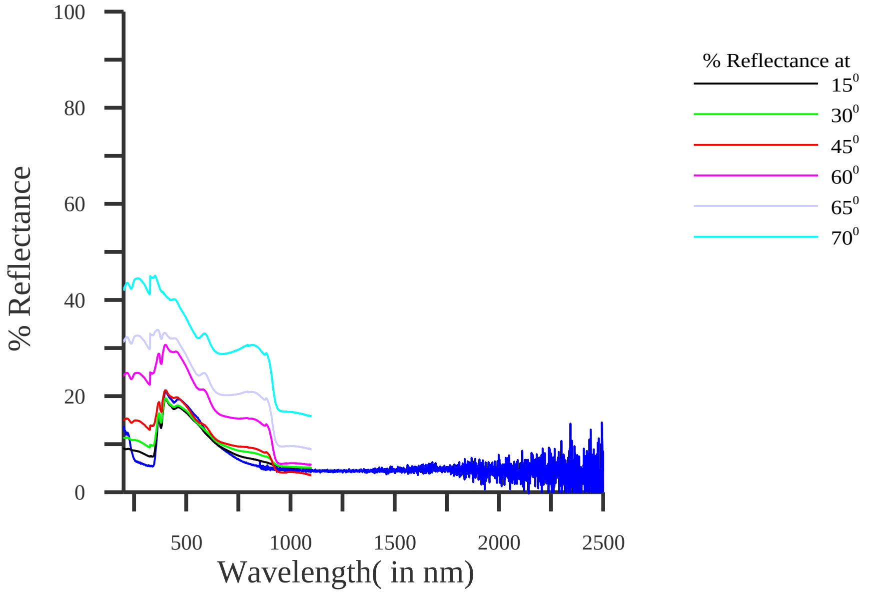


Fig 4.72: % Reflectance vs Wavelength for non-coated side of sample ST 450

Glass Manufacturer: Saint Gobain
Sample: Cool-Lite Blue Green ST 450 CoatedSide

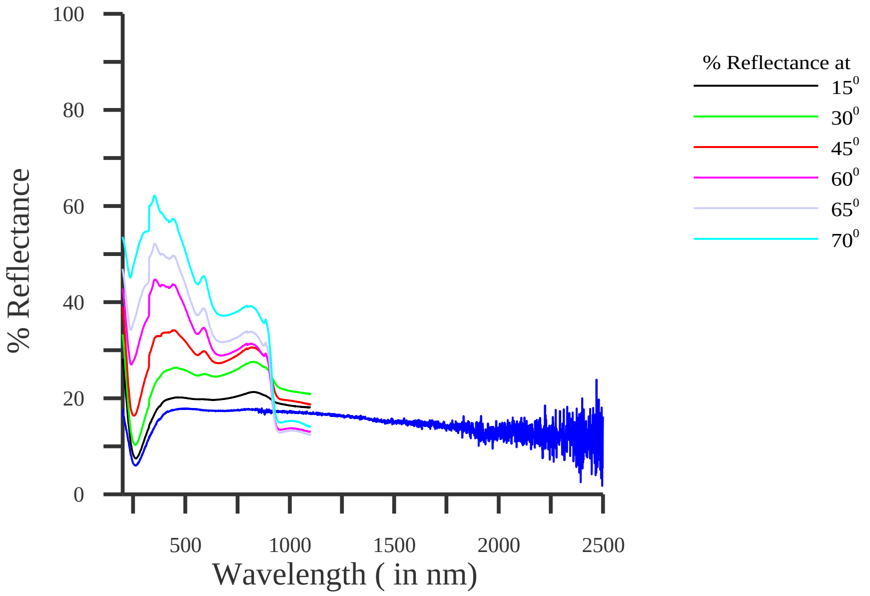


Fig 4.73: % Reflectance vs Wavelength for coated side of sample ST 450

Comparisons of the spectral reflectance measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range with Jasco V-770 Spectrophotometer in UV- vis- Nir range is shown in Fig. 4.72 and Fig. 4.73. The reflectance characteristics measured by Jasco V-770 Spectrophotometer shows almost the same characteristics measured by Perkin-Elmer instrument. The reflectance characteristics measured by Jasco V-770 Spectrophotometer shows some fluctuation in infrared range and these fluctuation increases with increase in wavelength in infrared range as seen in Fig. 4.72 and Fig 4.73.

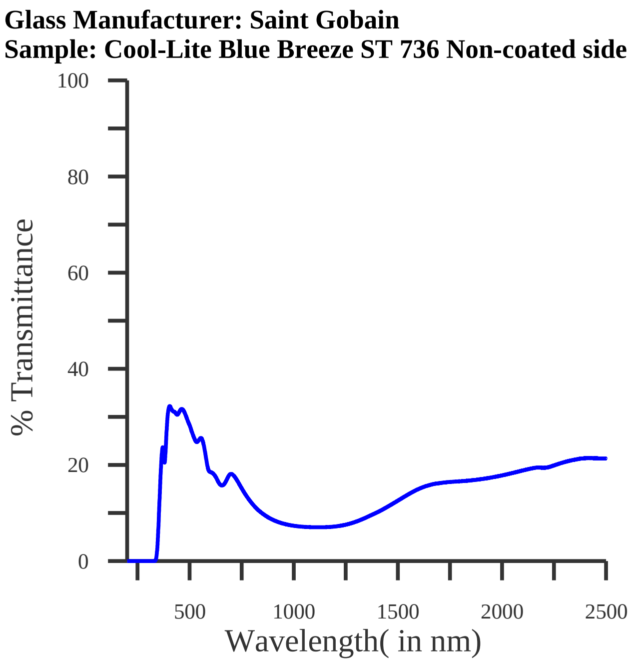


Fig 4.74: % Transmittance vs Wavelength for non-coated side of sample ST 736

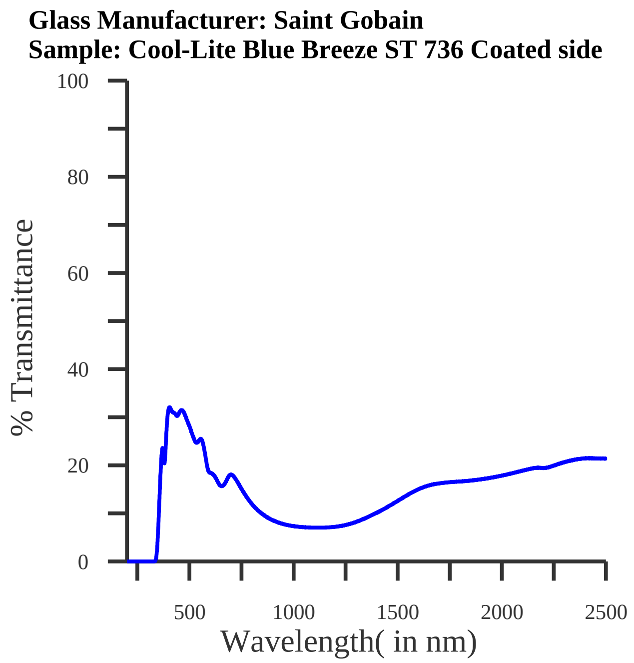


Fig 4.75: % Transmittance vs Wavelength for coated side of sample ST 736

From Fig.4.74 and 4.75 we can see that the nature of the curve shows a sharp increase up to 400 nm and then decreases at a slower rate till 1100 nm and then increases with increase in wavelength. The transmittance of Fig. 4.74 and Fig. 4.75 are measured by Jasco V-770 Spectrophotometer in UV- vis-Nir range for fixed incident angle. The transmittance characteristic of Fig. 4.74 and Fig.4.75 shows almost same characteristics as measured by Perkin-Elmer instrument while comparing these two figures with Fig. 4.50 and Fig. 4.51 in UV-vis range.

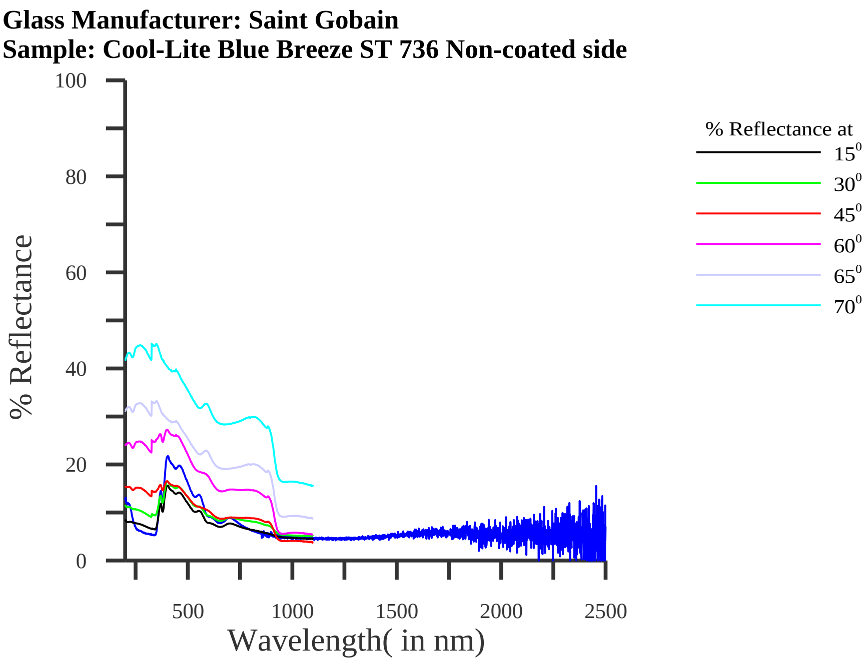


Fig 4.76: % Reflectance vs Wavelength for Non-coated side of sample ST 736

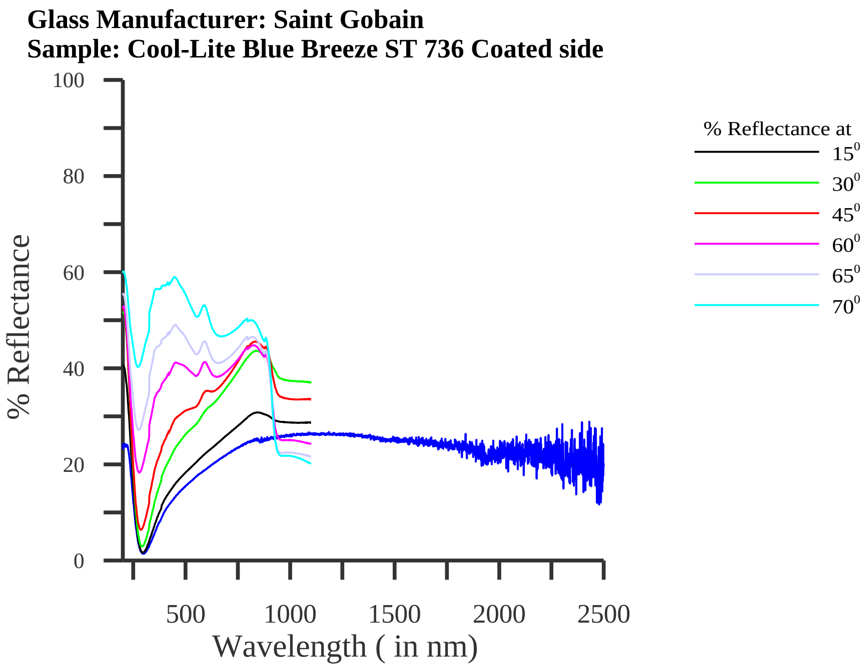


Fig 4.77: % Reflectance vs Wavelength for coated side of sample ST 736

Comparisons of the spectral reflectance measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range with Jasco V-770 Spectrophotometer in UV- vis- Nir range is shown in Fig. 4.76 and Fig. 4.77. The reflectance characteristics measured by Jasco V-770 Spectrophotometer shows almost the same characteristics measured by Perkin-Elmer instrument. The reflectance characteristics measured by Jasco V-770 Spectrophotometer shows some fluctuation in infrared range and these fluctuation increases with increase in wavelength in infrared range as seen in Fig. 4.76 and Fig 4.77.

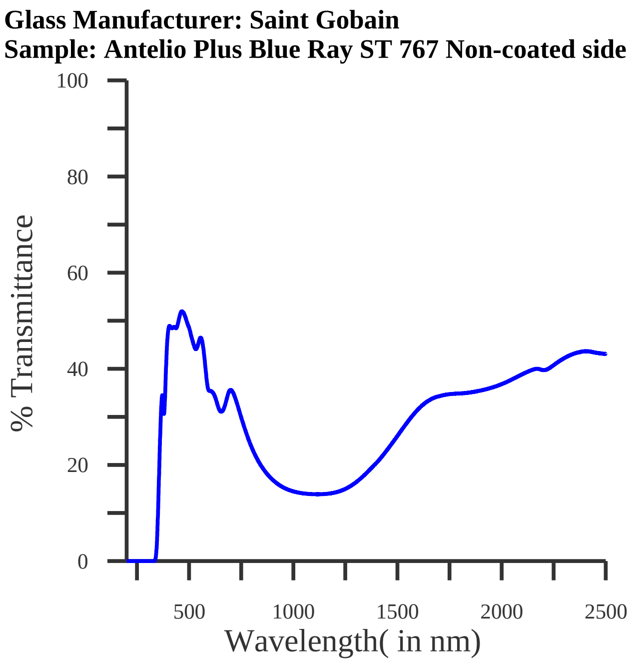


Fig 4.78: % Transmittance vs Wavelength for non-coated side of sample ST 767

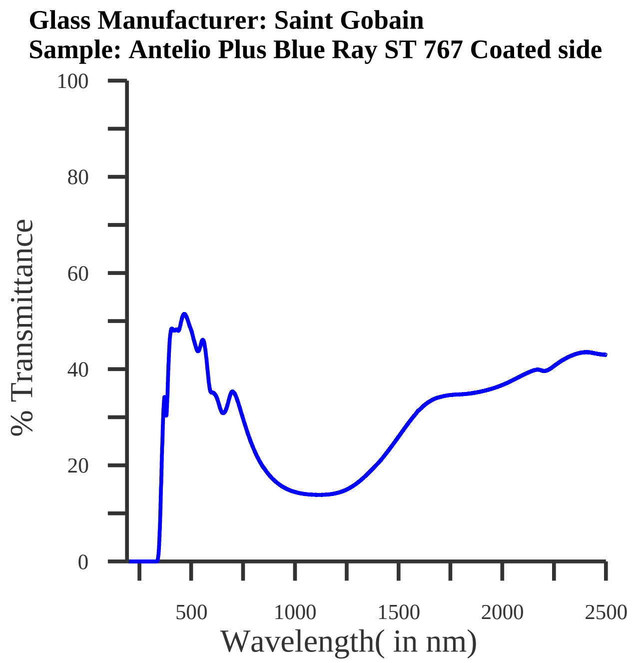


Fig 4.79: % Transmittance vs Wavelength for coated side of sample ST 767

From Fig.4.78 and 4.79 we can see that the nature of the curve shows a sharp increase up to 500 nm and then decreases at a slower rate till 1100 nm and then increases with increase in wavelength. The transmittance of Fig. 4.78 and Fig. 4.79 are measured by Jasco V-770 Spectrophotometer in UV- vis-Nir range for fixed incident angle. The transmittance characteristic of Fig. 4.78 and Fig.4.79 shows almost same characteristics as measured by Perkin-Elmer instrument while comparing these two figures with Fig. 4.58 and Fig. 4.59 in UV-vis range.

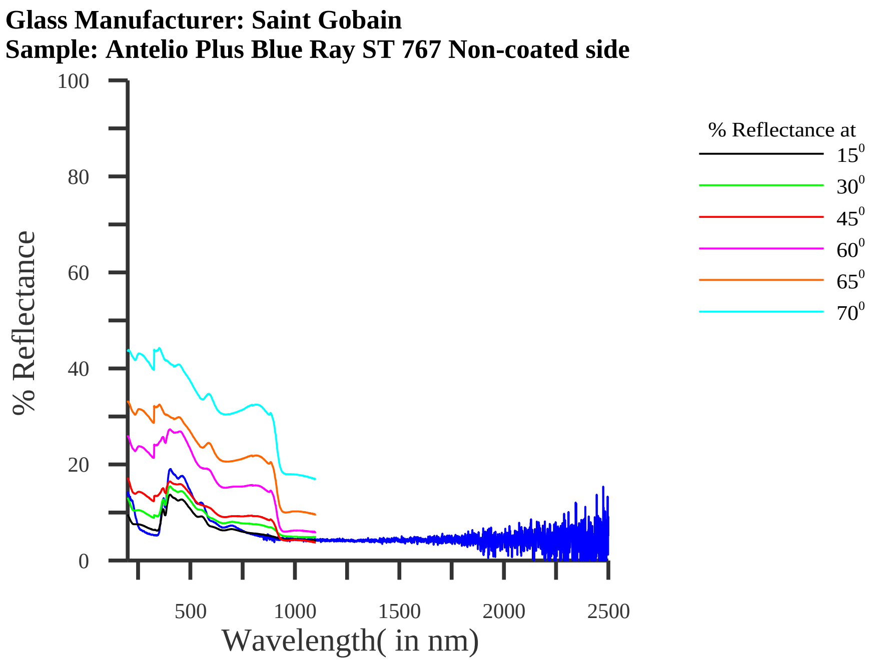


Fig 4.80: % Reflectance vs Wavelength for non-coated side of sample ST 767

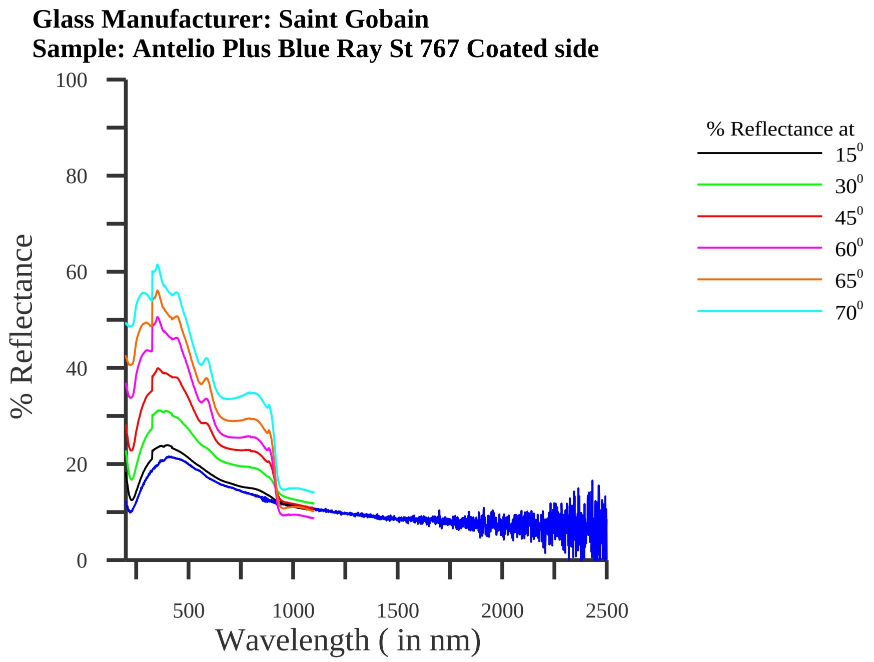


Fig 4.81: % Reflectance vs Wavelength for coated side of sample ST 767

Comparisons of the spectral reflectance measured by Perkin- Elmer Lambda-35 Spectrophotometer in UV- vis range with Jasco V-770 Spectrophotometer in UV- vis- Nir range is shown in Fig. 4.80 and Fig. 4.81. The reflectance characteristics measured by Jasco V-770 Spectrophotometer shows almost the same characteristics measured by Perkin-Elmer instrument. The reflectance characteristics measured by Jasco V-770 Spectrophotometer shows some fluctuation in infrared range and these fluctuation increases with increase in wavelength in infrared range as seen in Fig. 4.80 and Fig 4.81.

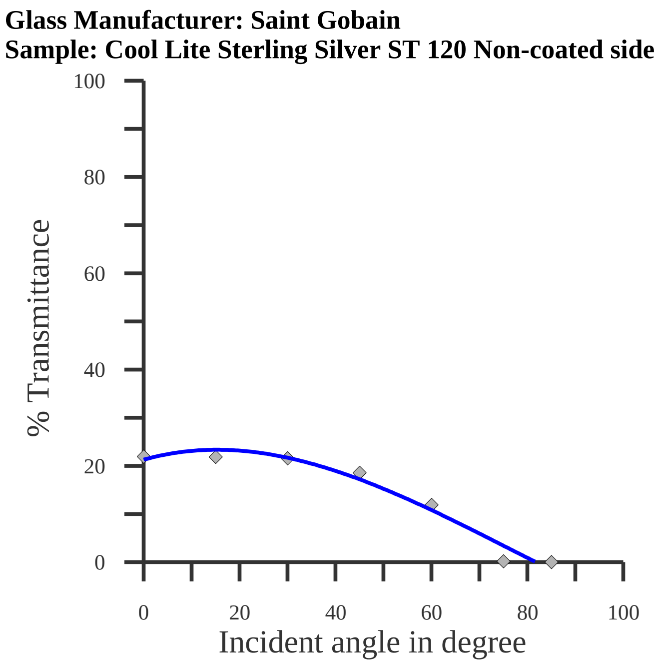


Fig 4.82: % Transmittance vs Incident angle in degree curve for non-coated side of sample ST 120

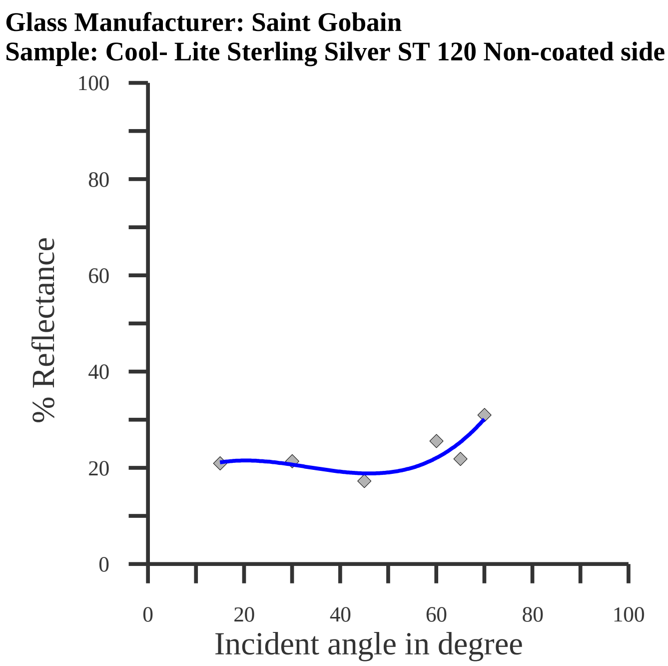


Fig 4.83: % Reflectance vs Incident angle in degree curve for non-coated side of sample ST 120

From Fig. 4.82 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.83 we can see that % reflectance curve remains almost same from 15^0 to 45^0 and then increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

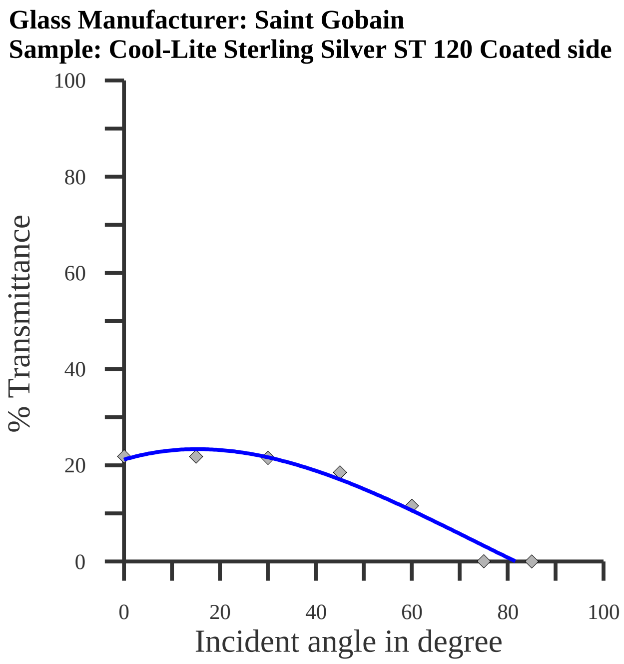


Fig 4.84: % Transmittance vs Incident angle in degree curve for coated side of sample ST 120

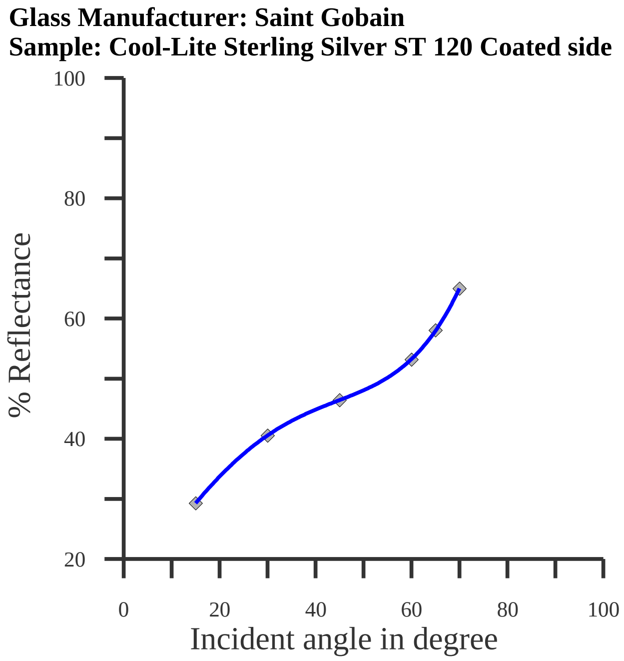


Fig 4.85: % Reflectance vs Incident angle in degree curve for coated side of sample ST 120

From Fig. 4.84 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.85 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.85 with Fig. 4.83. The reason could be coating which is present on one side of glazing sample.

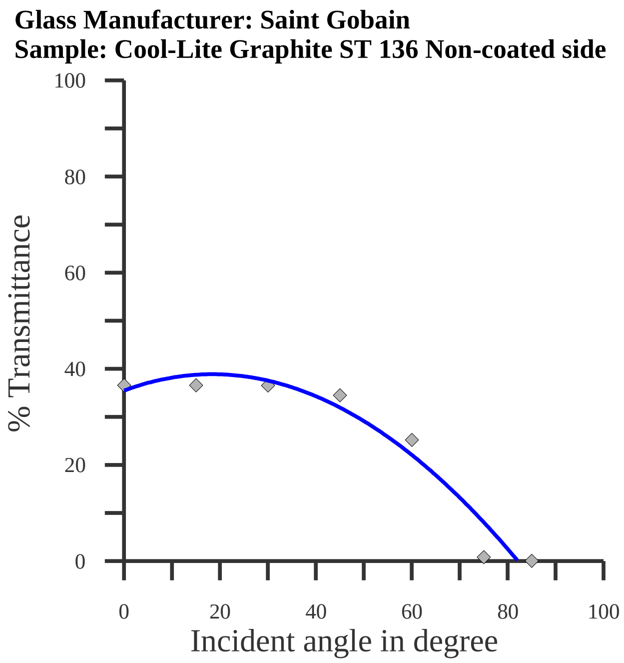


Fig 4.86: % Transmittance vs Incident angle in degree curve for non-coated side of sample ST 136

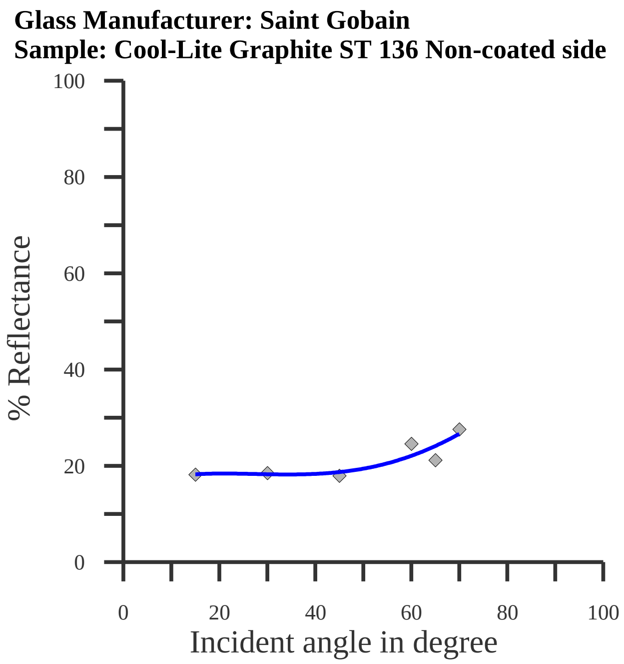


Fig 4.87: % Reflectance vs Incident angle in degree curve for non-coated side of sample ST 136

From Fig. 4.86 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.87 we can see that % reflectance curve remains almost same from 15^0 to 45^0 and then increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

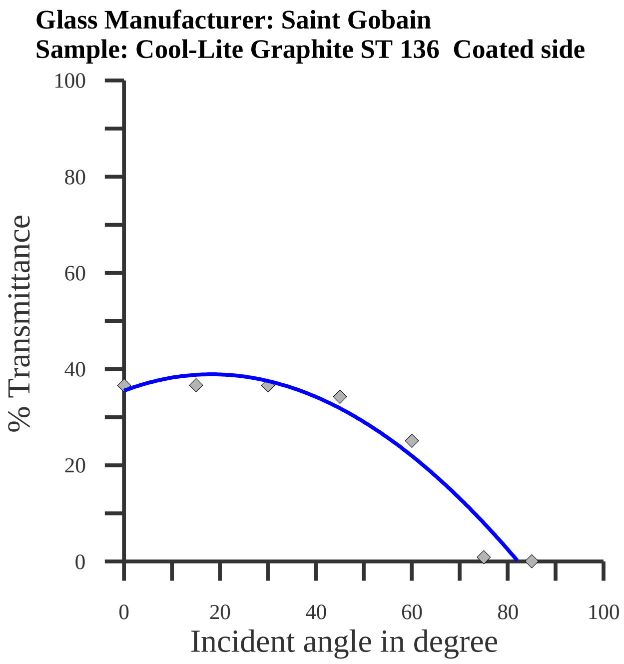


Fig 4.88: % Transmittance vs Incident angle in degree curve for coated side of sample ST 136

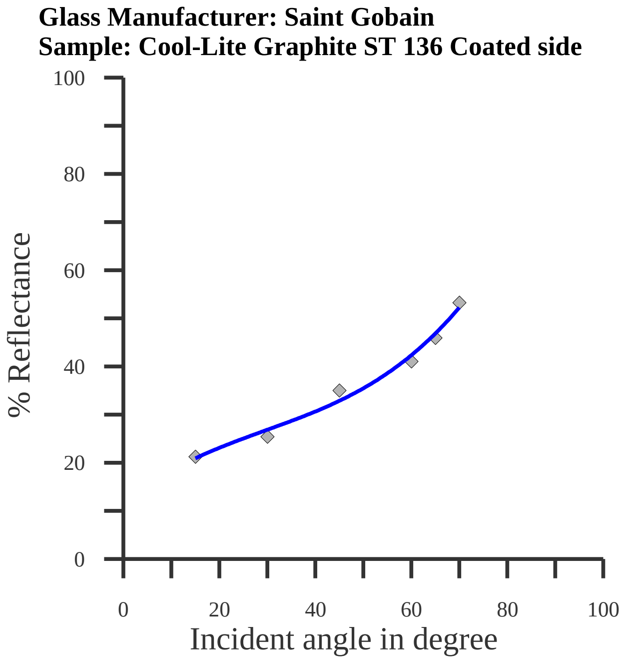


Fig 4.89: % Reflectance vs Incident angle in degree curve for coated side of sample ST 136

From Fig. 4.88 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.89 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.89 with Fig. 4.87. The reason could be coating which is present on one side of glazing sample.

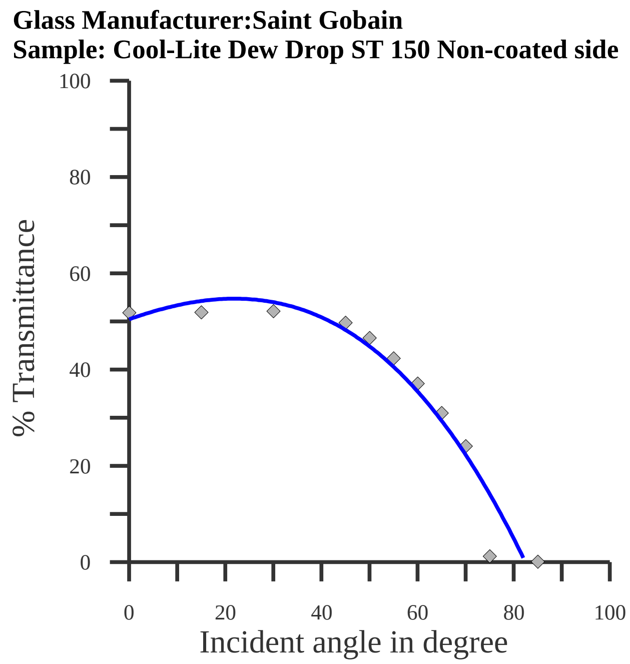


Fig 4.90: % Transmittance vs Incident angle in degree curve for non-coated side of sample ST 150

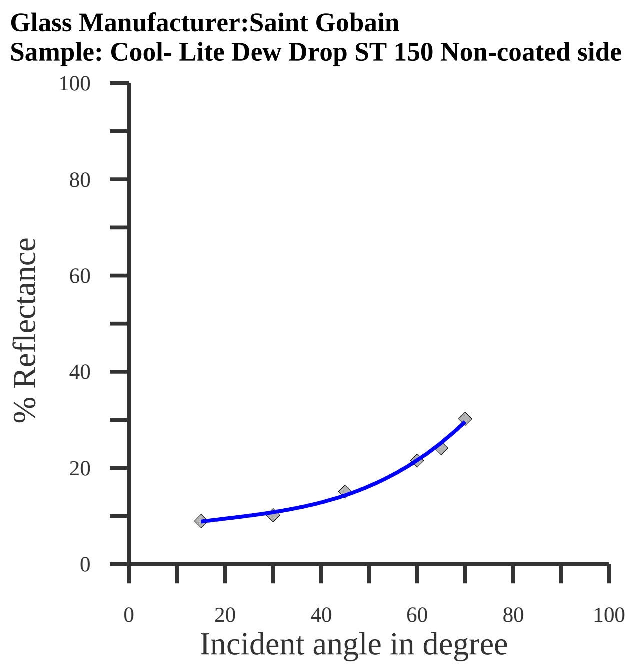


Fig 4.91: % Reflectance vs Incident angle in degree curve for non-coated side of sample ST 150

From Fig. 4.90 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.91 we can see that % reflectance curve increases with the increase of incidence angle from 15^0 to 70^0. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

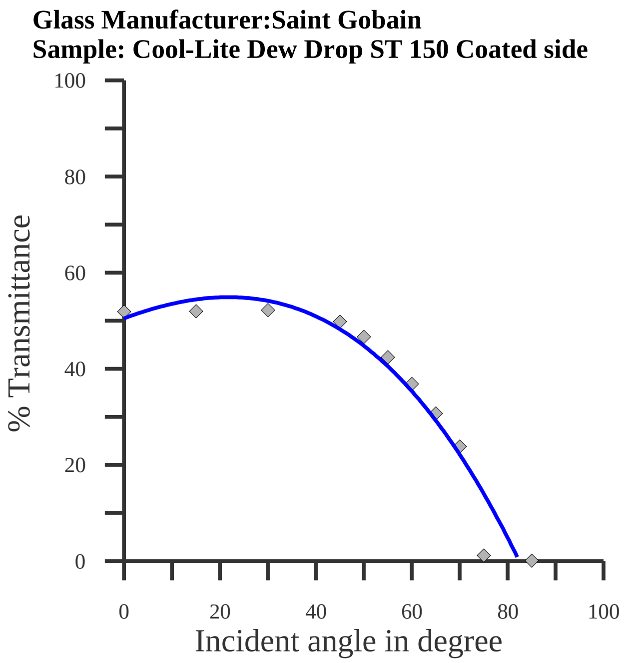


Fig 4.92: % Transmittance vs Incident angle in degree curve for coated side of sample ST 150

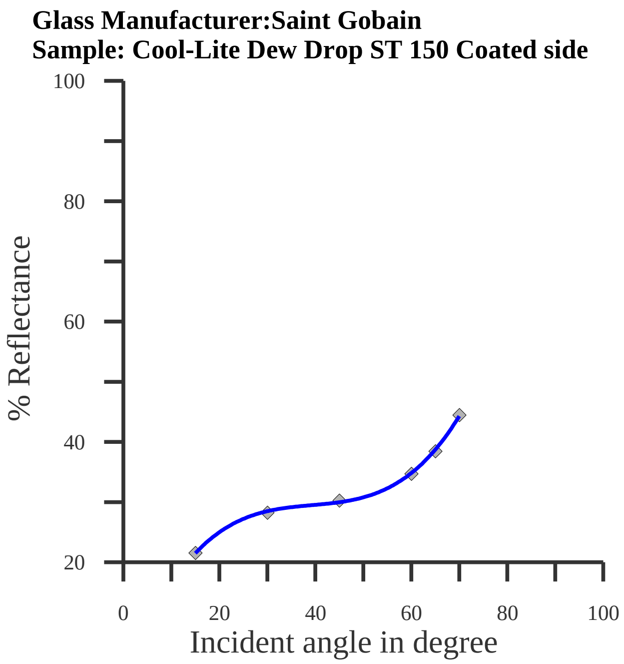


Fig 4.93: % Reflectance vs Incident angle in degree curve for coated side of sample ST 150

From Fig. 4.92 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.93 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.93 with Fig. 4.91. The reason could be coating which is present on one side of glazing sample.

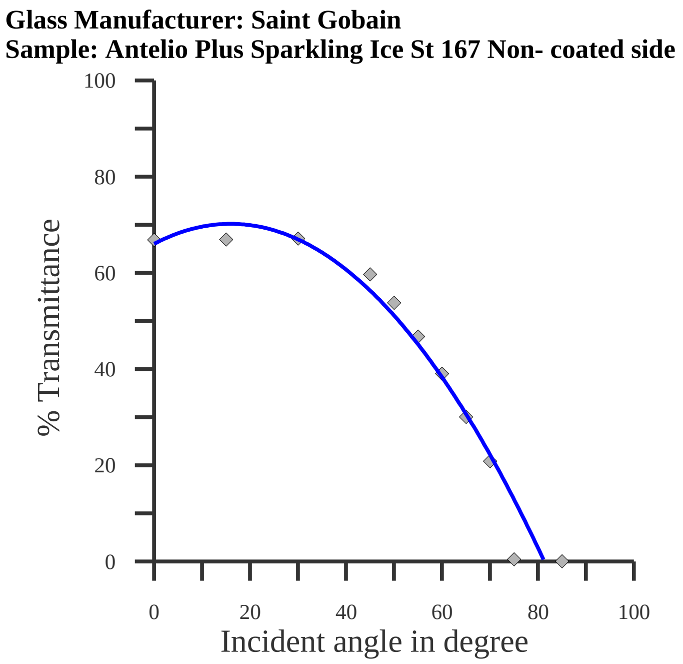


Fig 4.94: % Transmittance vs Incident angle in degree curve for non-coated side of sample ST 167

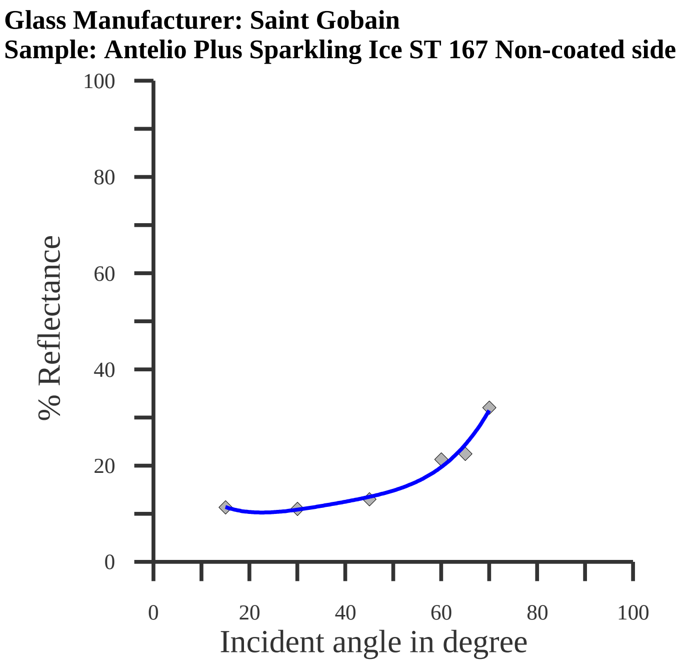


Fig 4.95: % Reflectance vs Incident angle in degree curve for non-coated side of sample ST 167

From Fig. 4.94 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.95 we can see that % reflectance curve increases with the increase of incidence angle from 15^0 to 70^0. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

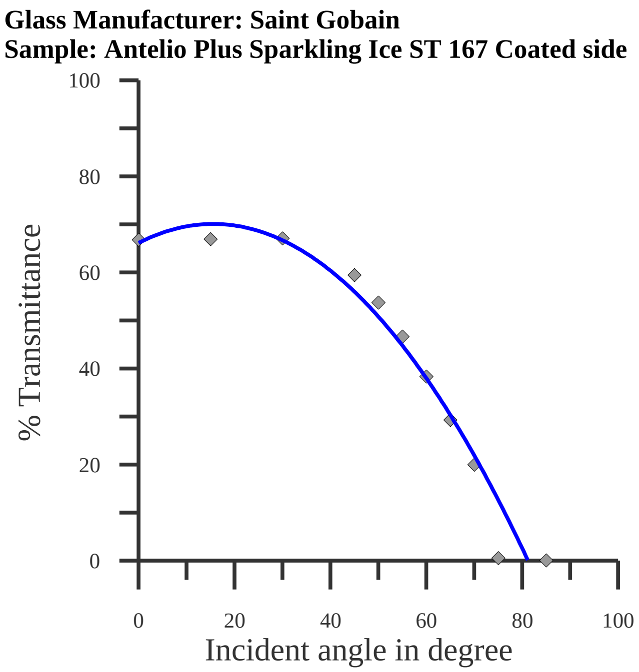


Fig 4.96: % Transmittance vs Incident angle in degree curve for coated side of sample ST 167

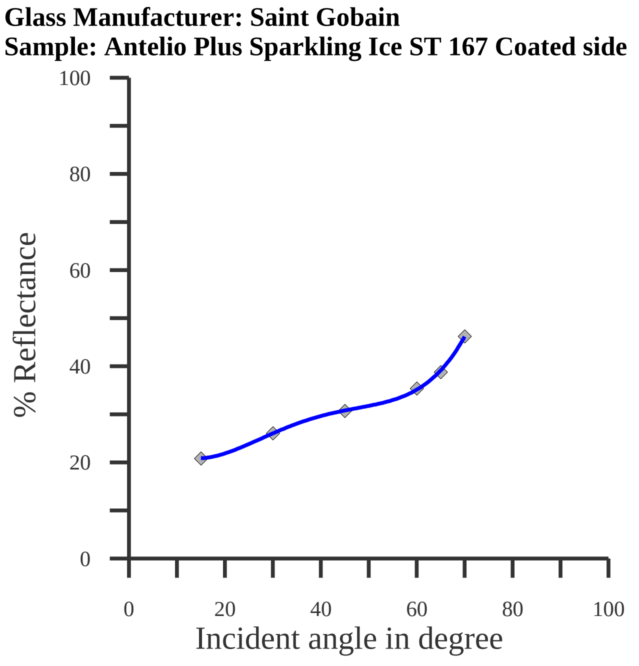


Fig 4.97: % Reflectance vs Incident angle in degree curve for coated side of sample ST 167

From Fig. 4.96 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.97 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.97 with Fig. 4.95. The reason could be coating which is present on one side of glazing sample.

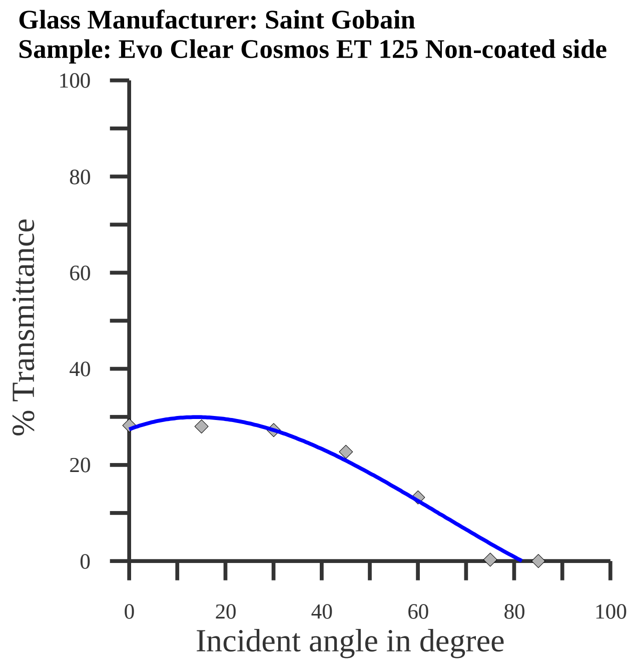


Fig 4.98: % Transmittance vs Incident angle in degree curve for non-coated side of sample ET 125

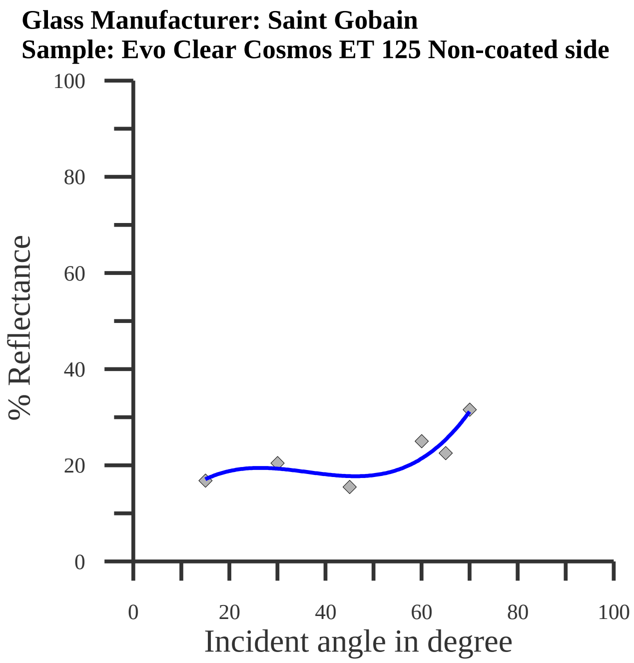


Fig 4.99: % Reflectance vs Incident angle in degree curve for non-coated side of sample ET 125

From Fig. 4.98 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.99 we can see that % reflectance curve remains almost same from 15^0 to 45^0 and then increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

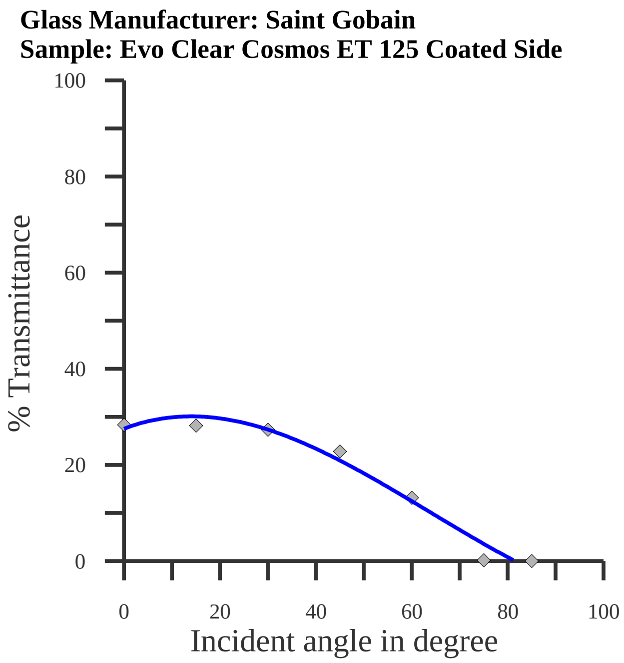


Fig 4.100: % Transmittance vs Incident angle in degree curve for coated side of sample ET 125

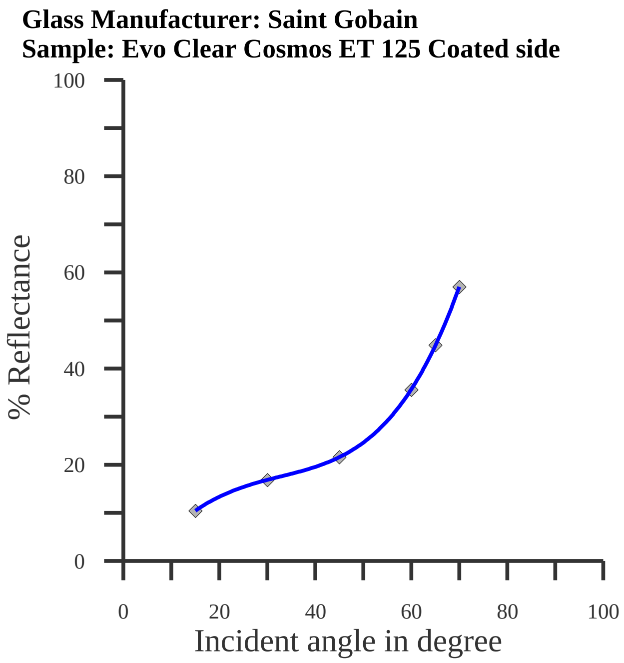


Fig 4.101: % Reflectance vs Incident angle in degree curve for coated side of sample ET 125

From Fig. 4.100 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.101 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.101 with Fig. 4.99. The reason could be coating which is present on one side of glazing sample.

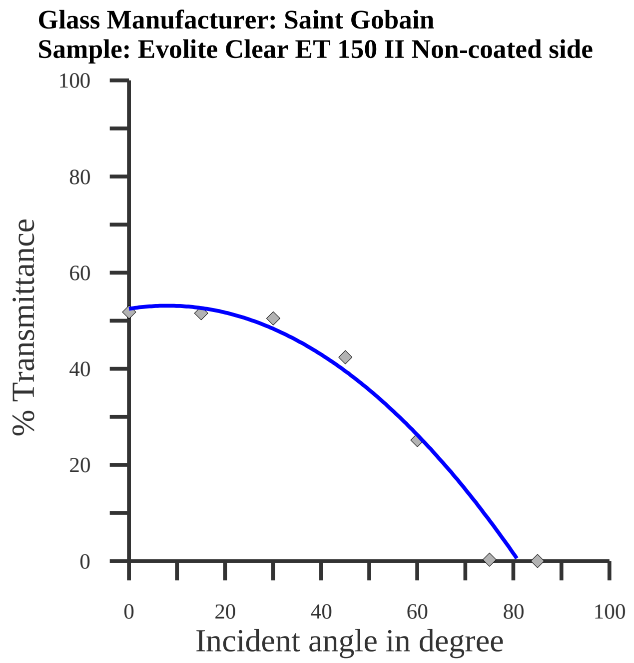


Fig 4.102: % Transmittance vs Incident angle in degree curve for non-coated side of sample ET 150 II

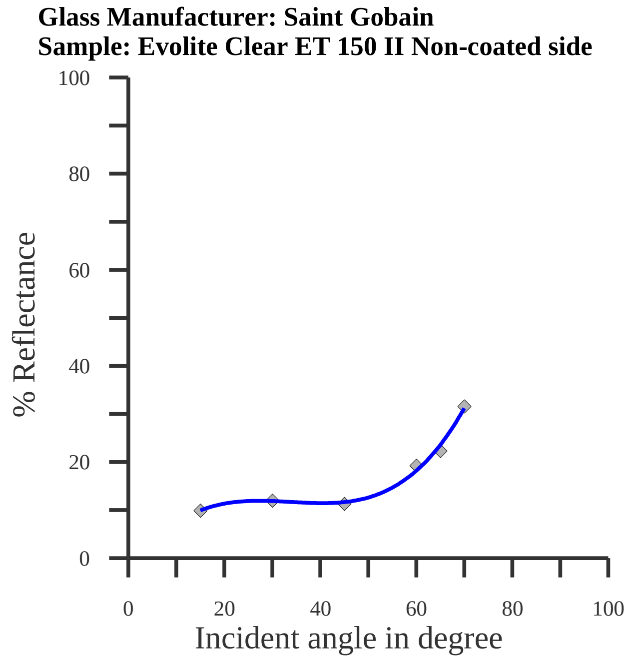


Fig 4.103: % Reflectance vs Incident angle in degree curve for non-coated side of sample ET 150 II

From Fig. 4.102 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.103 we can see that % reflectance curve remains almost same from 15^0 to 45^0 and then increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

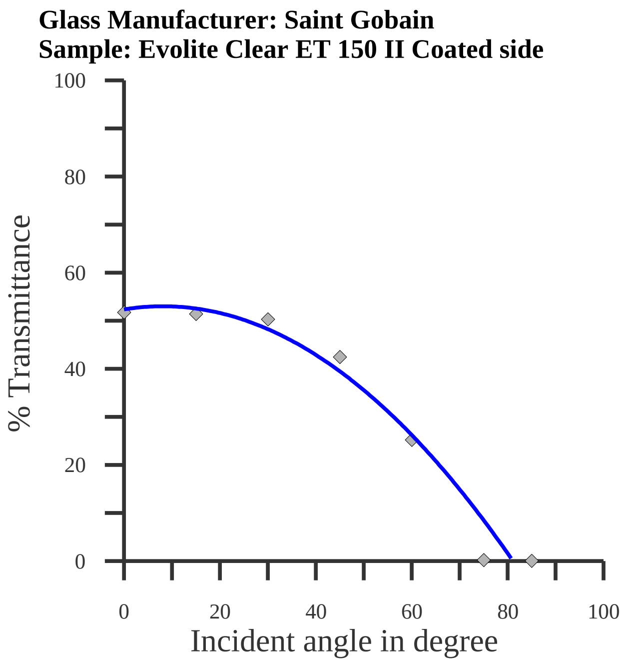


Fig 4.104: % Transmittance vs Incident angle in degree curve for coated side of sample ET 150 II

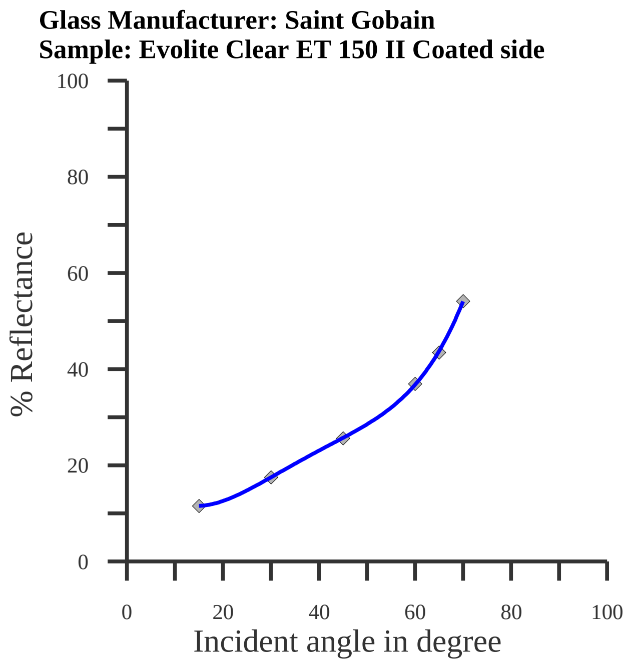


Fig 4.105: % Reflectance vs Incident angle in degree curve for coated side of sample ET 150 II

From Fig. 4.104 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.105 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.105 with Fig. 4.103. The reason could be coating which is present on one side of glazing sample.

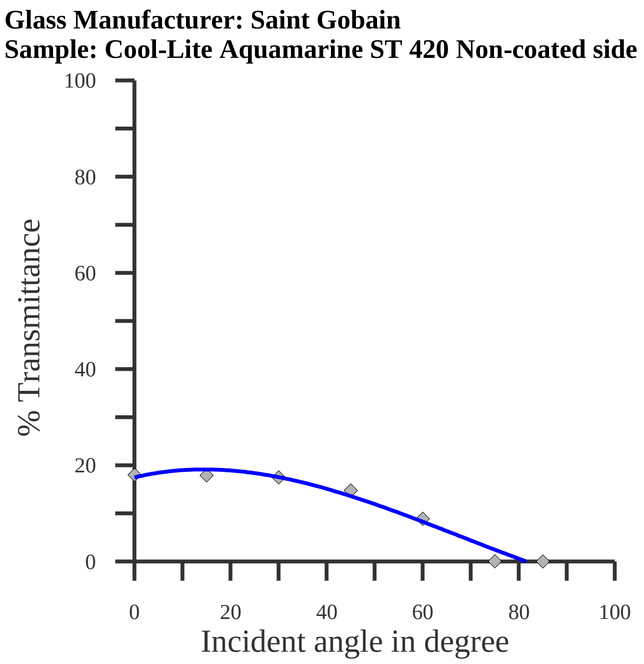


Fig 4.106: % Transmittance vs Incident angle in degree curve for non-coated side of sample ST 420

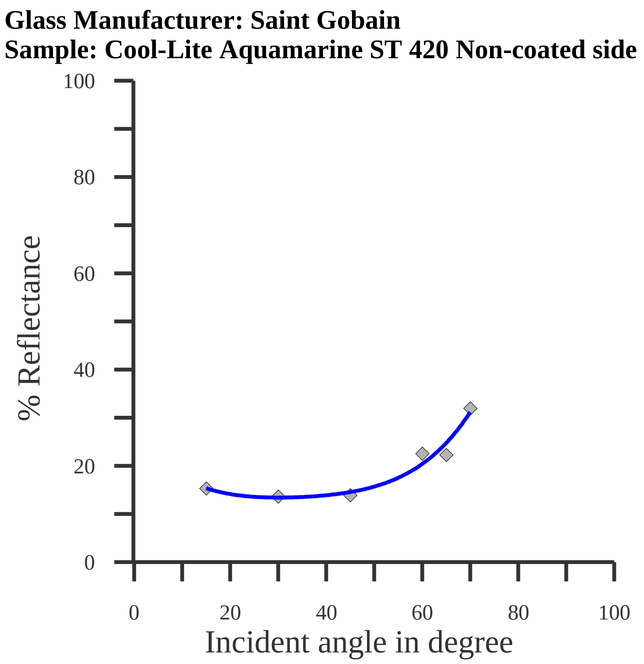


Fig 4.107: % Reflectance vs Incident angle in degree curve for non-coated side of sample ST 420

From Fig. 4.106 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.107 we can see that % reflectance curve remains almost same from 15^0 to 45^0 and then increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

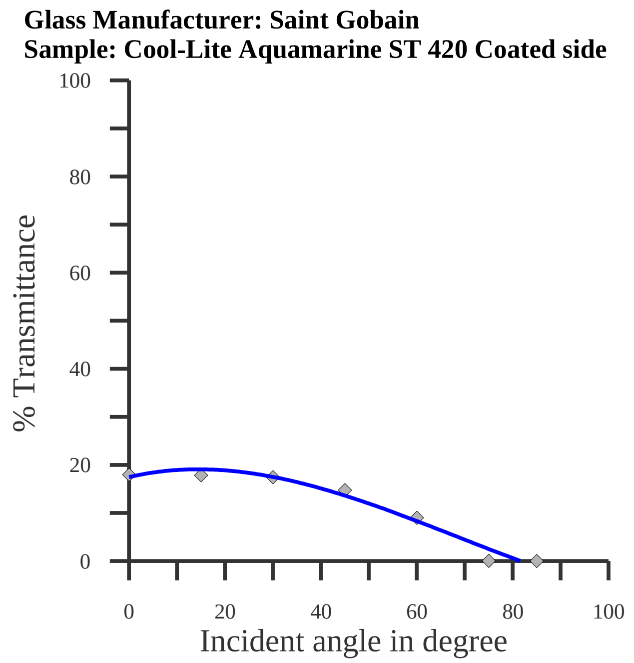


Fig 4.108: % Transmittance vs Incident angle in degree curve for coated side of sample ST 420

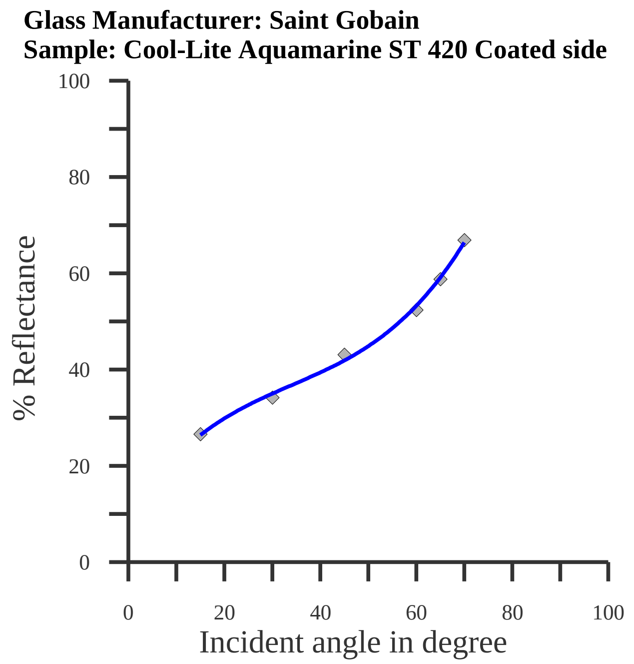


Fig 4.109: % Reflectance vs Incident angle in degree curve for coated side of sample ST 420

From Fig. 4.108 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.109 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.109 with Fig. 4.107. The reason could be coating which is present on one side of glazing sample.

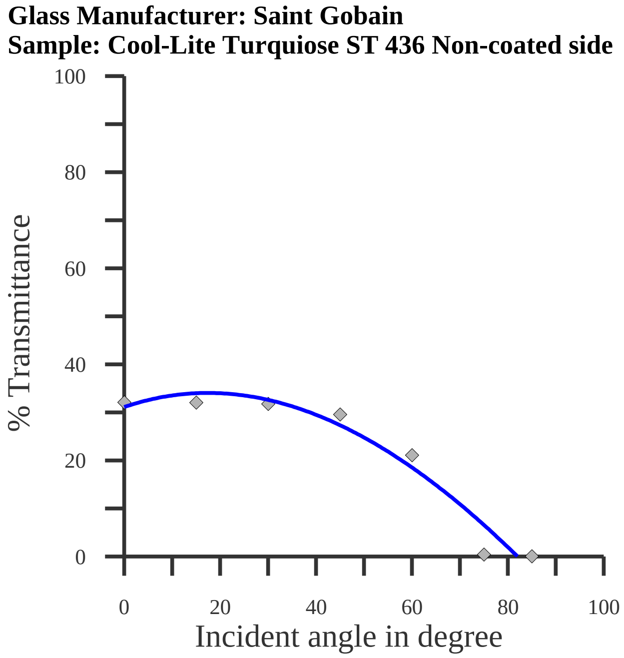


Fig 4.110: % Transmittance vs Incident angle in degree curve for non-coated side of sample ST 436

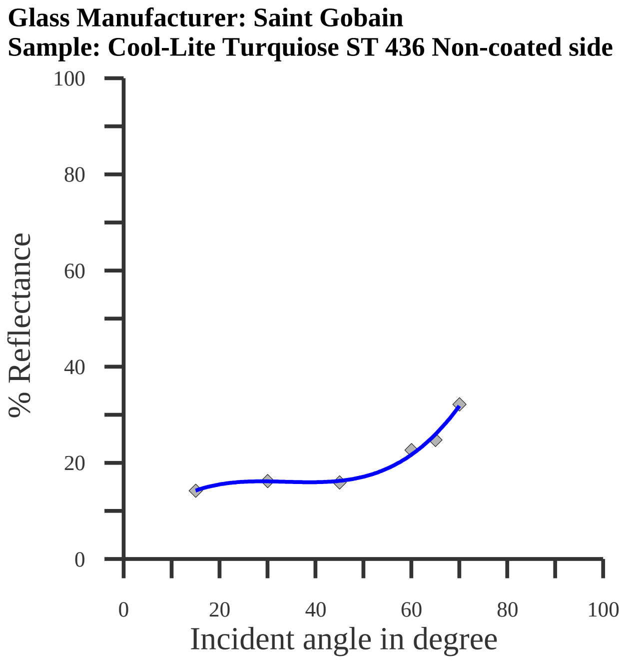


Fig 4.111: % Reflectance vs Incident angle in degree curve for non-coated side of sample ST 436

From Fig. 4.110 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.111 we can see that % reflectance curve remains almost same from 15^0 to 45^0 and then increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

Glass Manufacturer: Saint Gobain
Sample: Cool-Lite Turquiose ST 436 Coated side

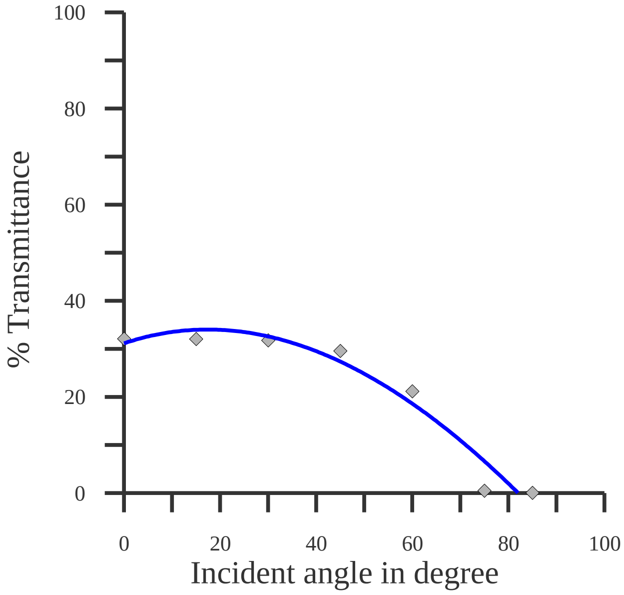


Fig 4.112: % Transmittance vs Incident angle in degree curve for coated side of sample ST 436

Glass Manufacturer: Saint Gobain
Sample: Cool-Lite Turquiose ST 436 Coated side

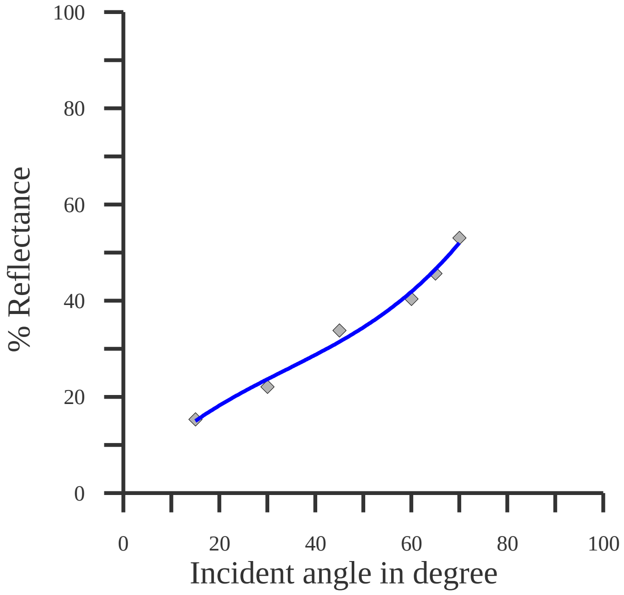


Fig 4.113: % Reflectance vs Incident angle in degree curve for coated side of sample ST 436

From Fig. 4.112 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.113 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.113 with Fig. 4.111. The reason could be coating which is present on one side of glazing sample.

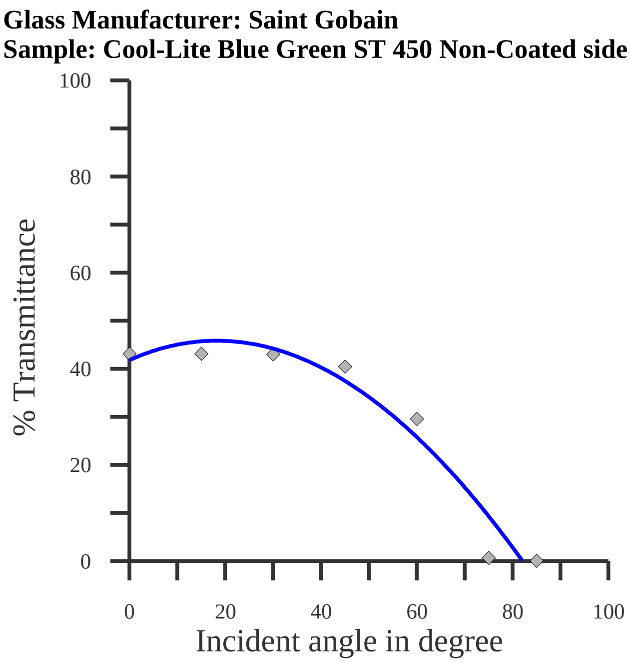


Fig 4.114: % Transmittance vs Incident angle in degree curve for non-coated side of sample ST 450

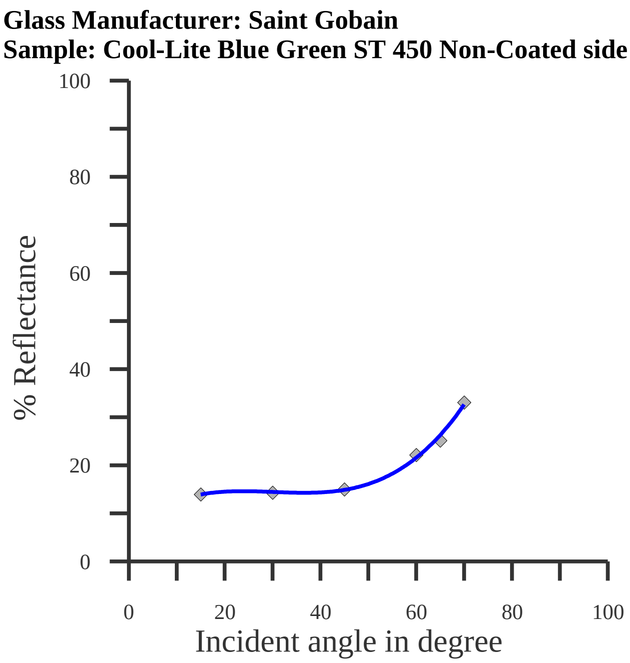


Fig 4.115: % Reflectance vs Incident angle in degree curve for non-coated side of sample ST 450

From Fig. 4.114 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.115 we can see that % reflectance curve remains almost same from 15^0 to 45^0 and then increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

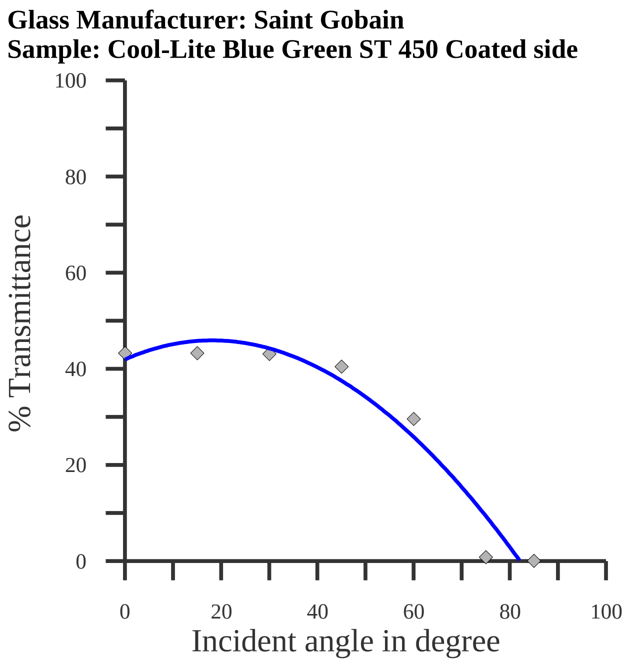


Fig 4.116: % Transmittance vs Incident angle in degree curve for coated side of sample ST 450

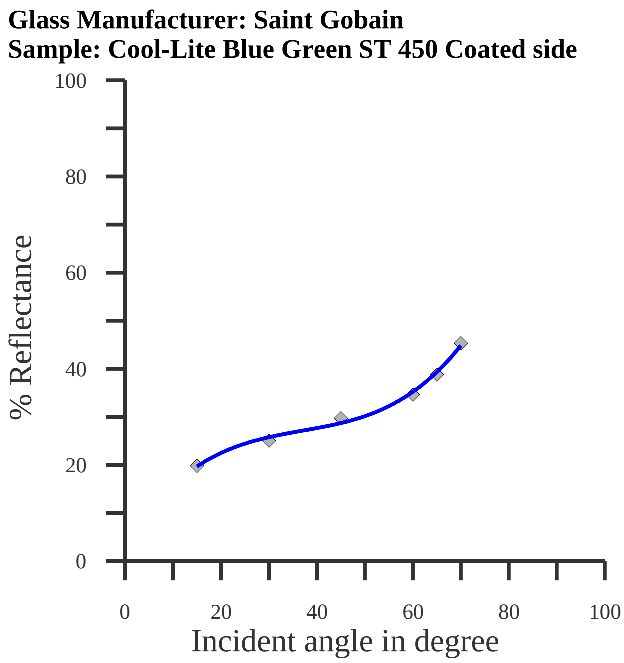


Fig 4.117: % Reflectance vs Incident angle in degree curve for coated side of sample ST 450

From Fig. 4.116 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.117 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.117 with Fig. 4.115. The reason could be coating which is present on one side of glazing sample.

Glass Manufacturer: Saint Gobain
Sample: Antelio Plus Emerald Glaze ST 467 Non-coated side

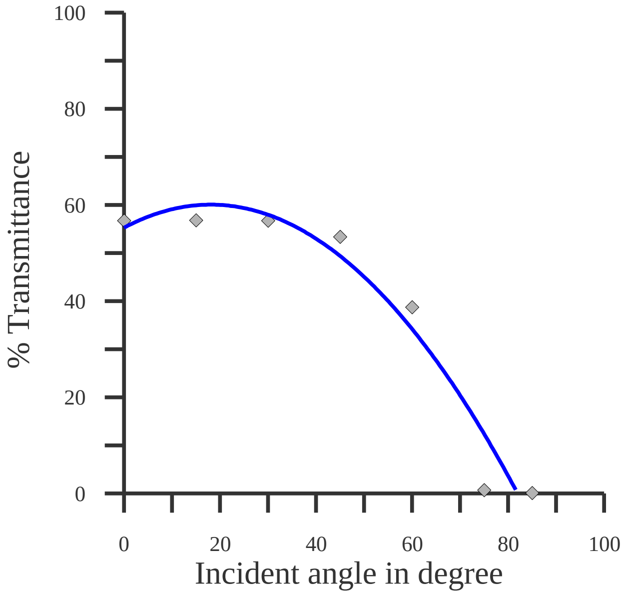


Fig 4.118: % Transmittance vs Incident angle in degree curve for non-coated side of sample ST 467

Glass Manufacturer: Saint Gobain
Sample: Antelio Plus Emerald Glaze ST 467 Non-coated side

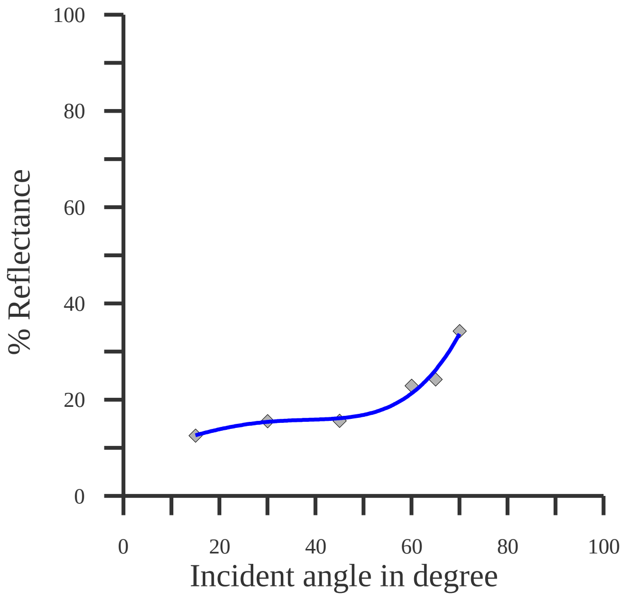


Fig 4.119: % Reflectance vs Incident angle in degree curve for non-coated side of sample ST 467

From Fig. 4.118 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.119 we can see that % reflectance curve increases with the increase of incidence angle from 15^0 to 70^0. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

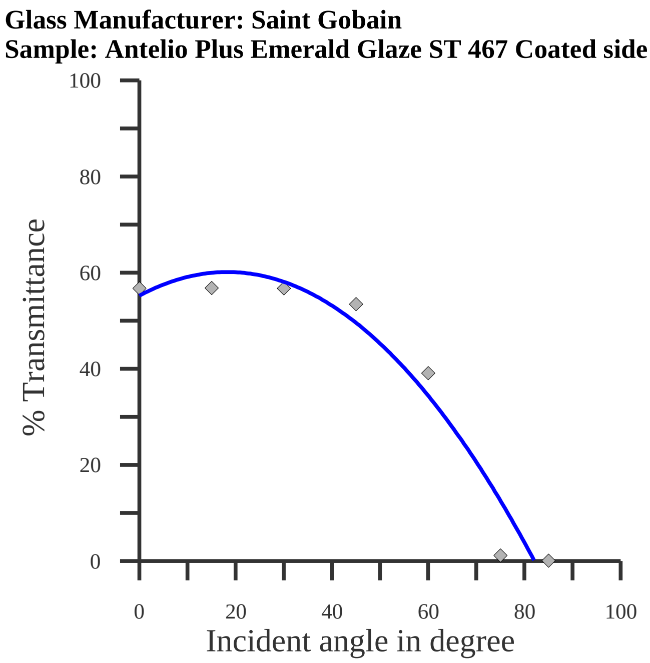


Fig 4.120: % Transmittance vs Incident angle in degree curve for coated side of sample ST 467

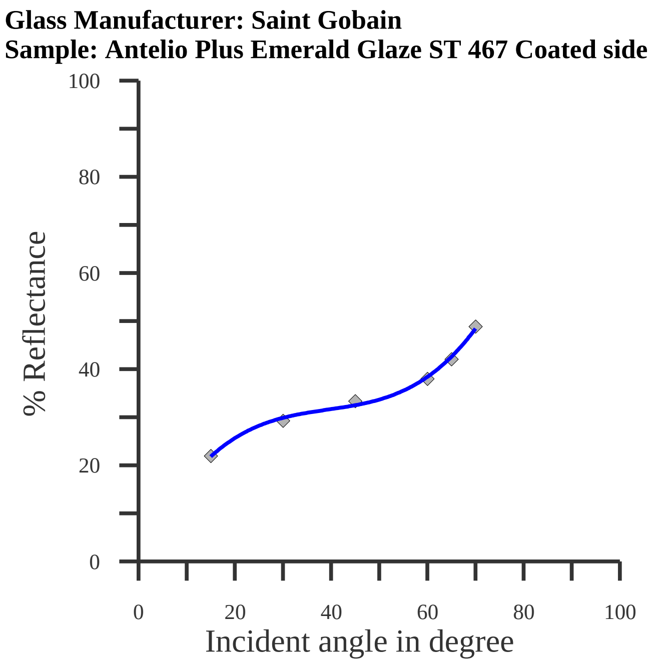


Fig 4.121: % Reflectance vs Incident angle in degree curve for coated side of sample ST 467

From Fig. 4.120 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.121 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.121 with Fig. 4.119. The reason could be coating which is present on one side of glazing sample.

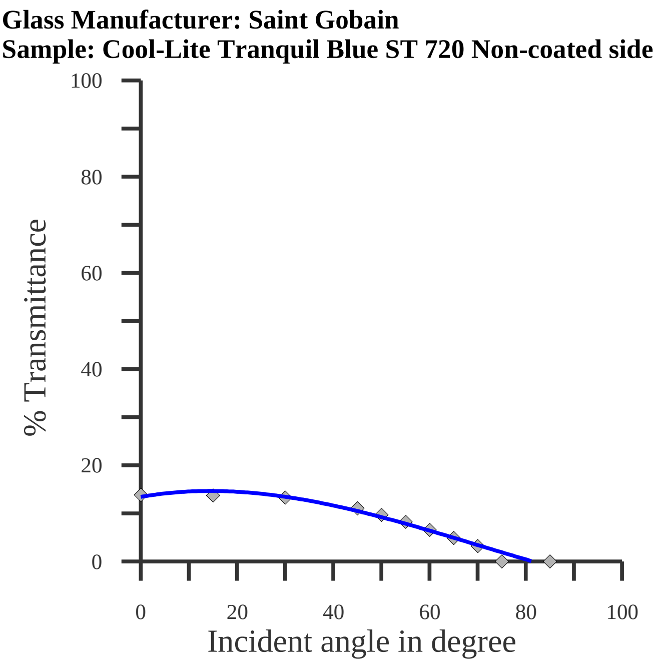


Fig 4.122: % Transmittance vs Incident angle in degree curve for non-coated side of sample ST 720

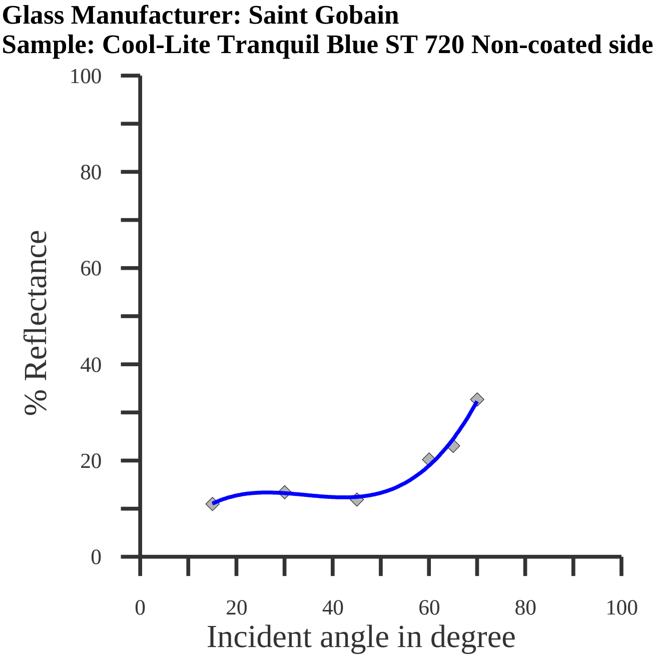


Fig 4.123: % Reflectance vs Incident angle in degree curve for non-coated side of sample ST 720

From Fig. 4.122 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.123 we can see that % reflectance curve remains almost same from 15^0 to 45^0 and then increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

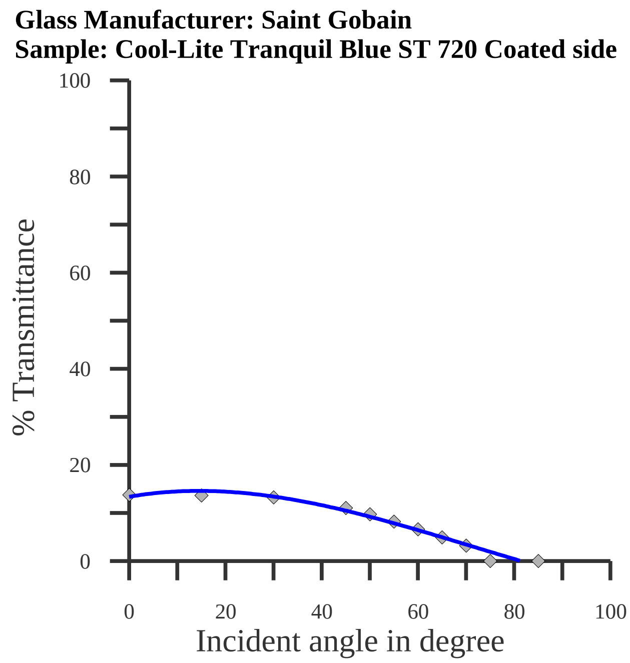


Fig 4.124: % Transmittance vs Incident angle in degree curve for coated side of sample ST 720

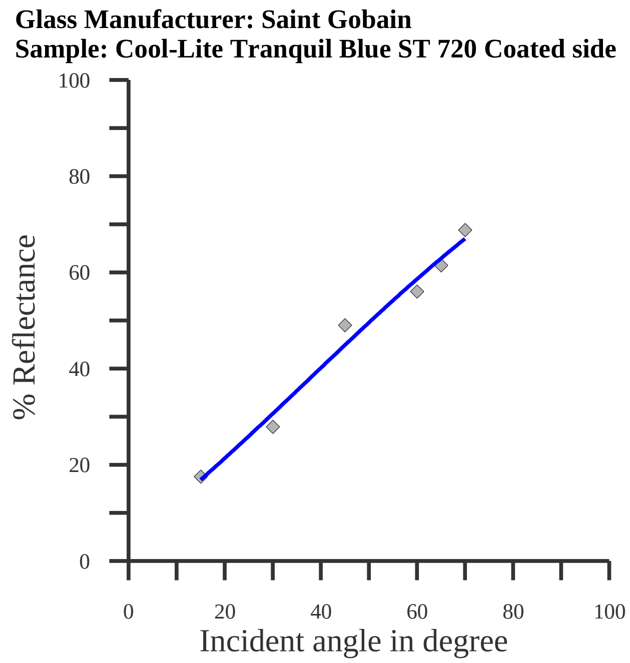


Fig 4.125: % Reflectance vs Incident angle in degree curve for coated side of sample ST 720

From Fig. 4.124 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.125 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.125 with Fig. 4.123. The reason could be coating which is present on one side of glazing sample.

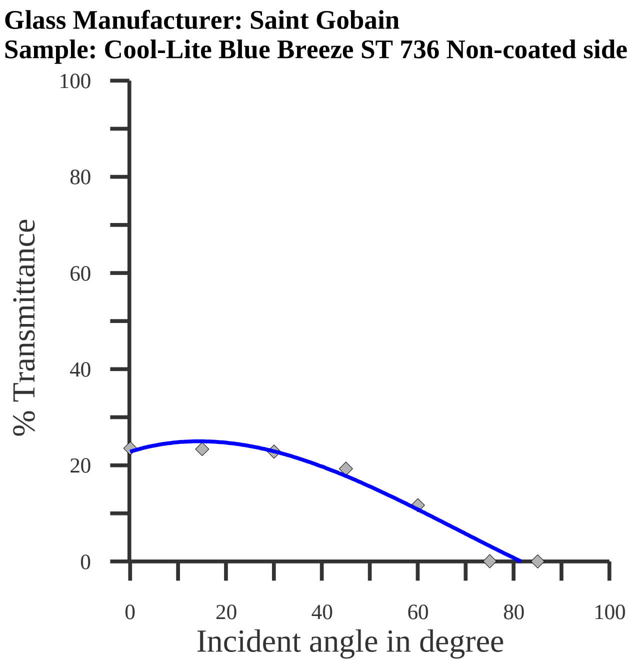


Fig 4.126: % Transmittance vs Incident angle in degree curve for non-coated side of sample ST 736

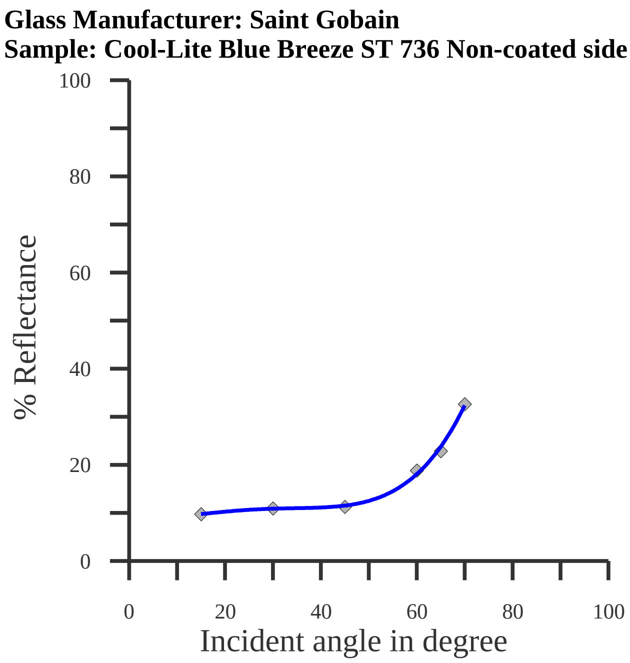


Fig 4.127: % Reflectance vs Incident angle in degree curve for non-coated side of sample ST 736

From Fig. 4.126 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.127 we can see that % reflectance curve remains almost same from 15^0 to 45^0 and then increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

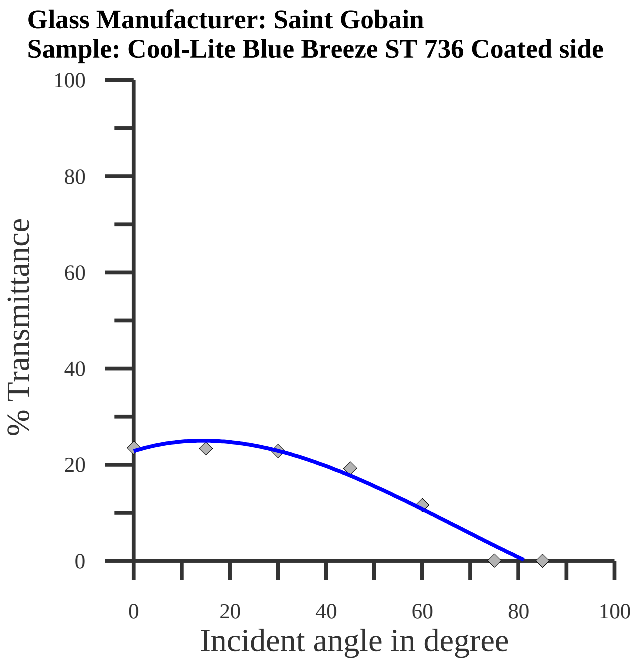


Fig 4.128: % Transmittance vs Incident angle in degree curve for coated side of sample ST 736

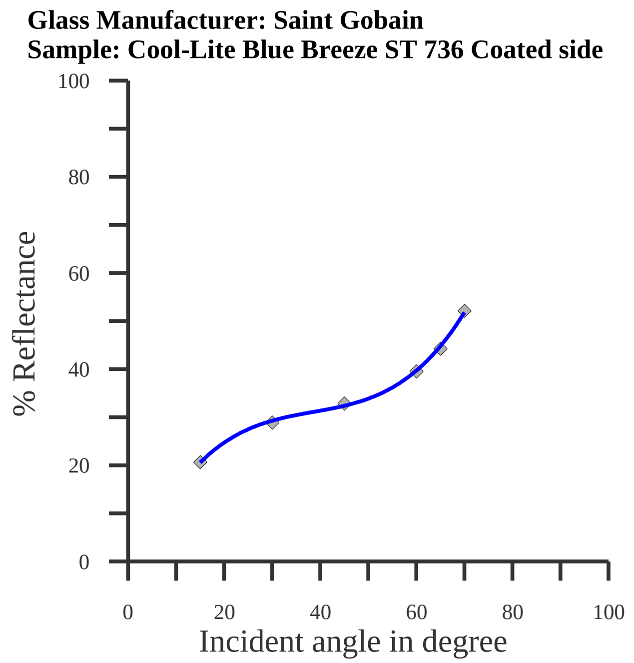


Fig 4.129: % Reflectance vs Incident angle in degree curve for coated side of sample ST 736

From Fig. 4.128 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.129 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.129 with Fig. 4.127. The reason could be coating which is present on one side of glazing sample.

Glass Manufacturer: Saint Gobain
Sample: Cool-Lite Royale Blue ST 750 Non-coated side

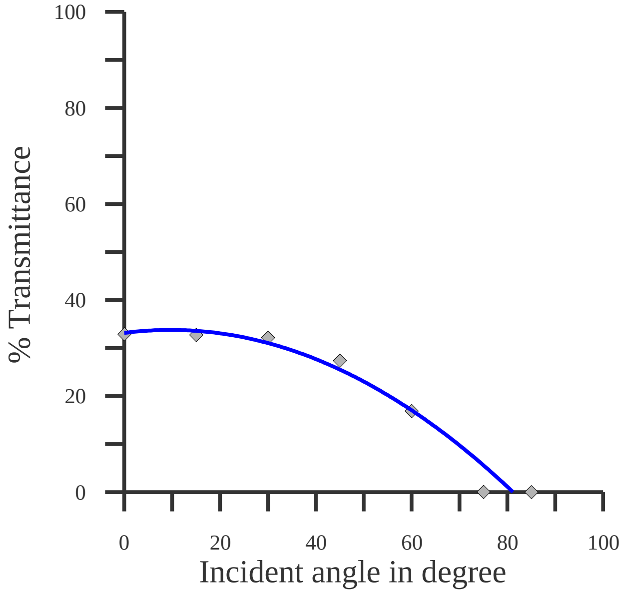


Fig 4.130: % Transmittance vs Incident angle in degree curve for non-coated side of sample ST 750

Glass Manufacturer: Saint Gobain
Sample: Cool-Lite Royale Blue ST 750 Non-coated side

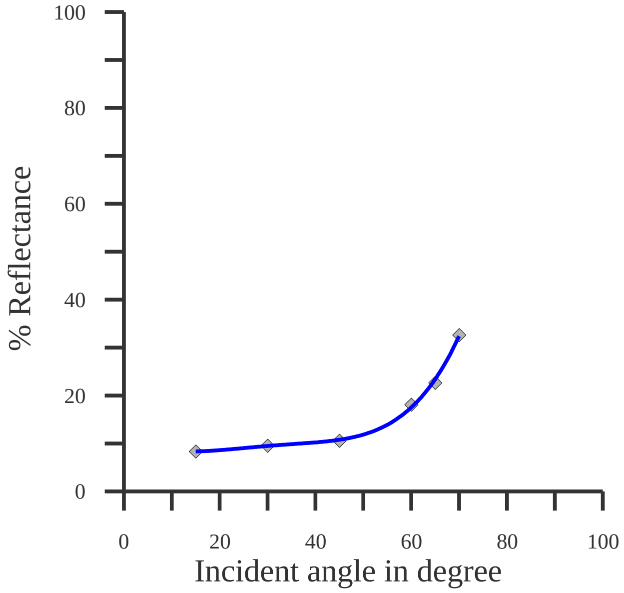


Fig 4.131: % Reflectance vs Incident angle in degree curve for non-coated side of sample ST 750

From Fig. 4.130 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.131 we can see that % reflectance curve remains almost same from 15^0 to 45^0 and then increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

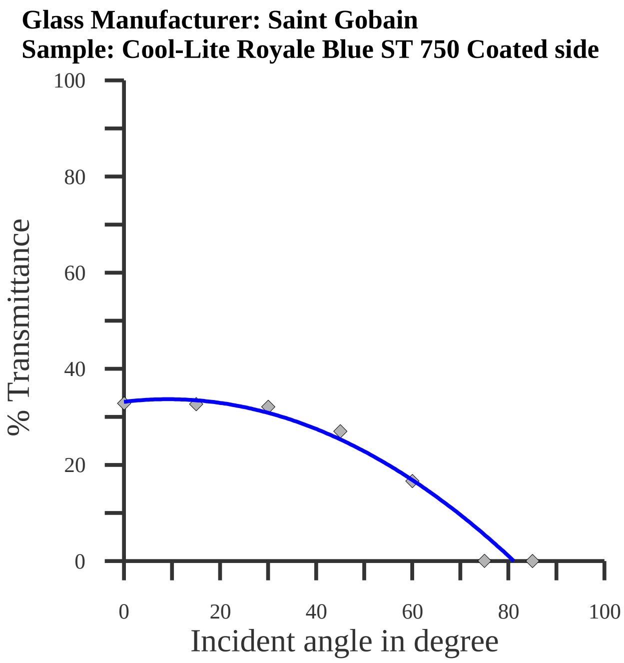


Fig 4.132: % Transmittance vs Incident angle in degree curve for coated side of sample ST 750

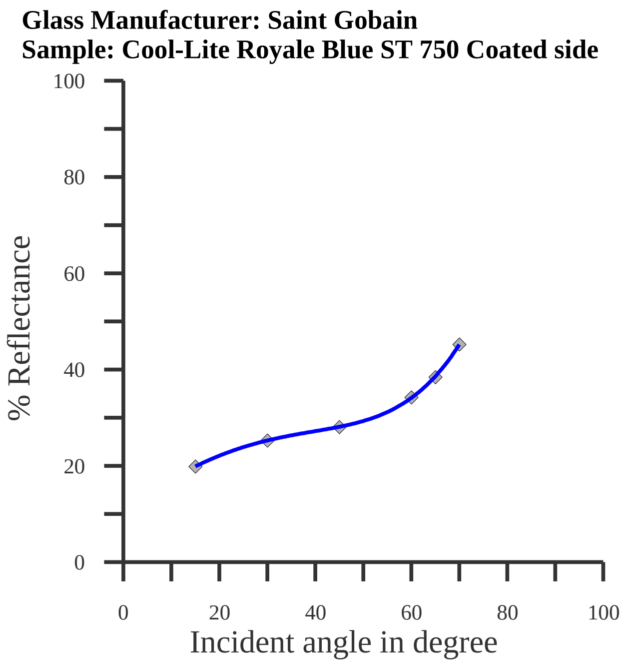


Fig 4.133: % Reflectance vs Incident angle in degree curve for coated side of sample ST 750

From Fig. 4.132 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.133 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.133 with Fig. 4.131. The reason could be coating which is present on one side of glazing sample.

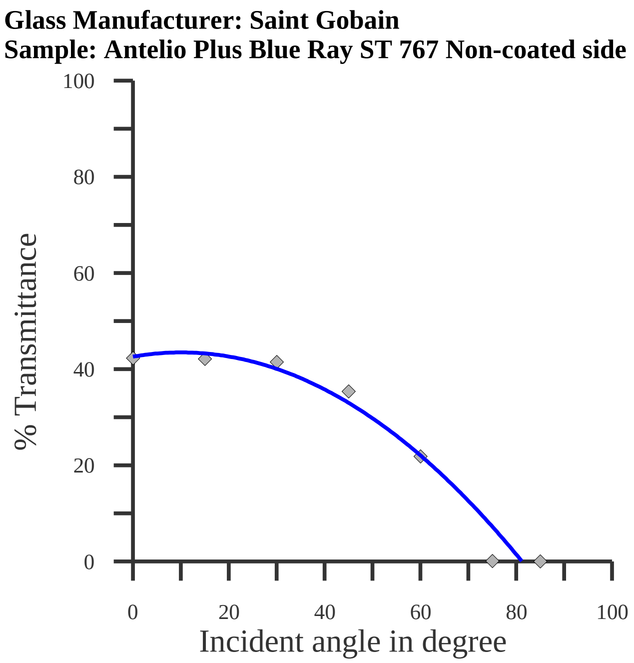


Fig 4.134: % Transmittance vs Incident angle in degree curve for non-coated side of sample ST 767

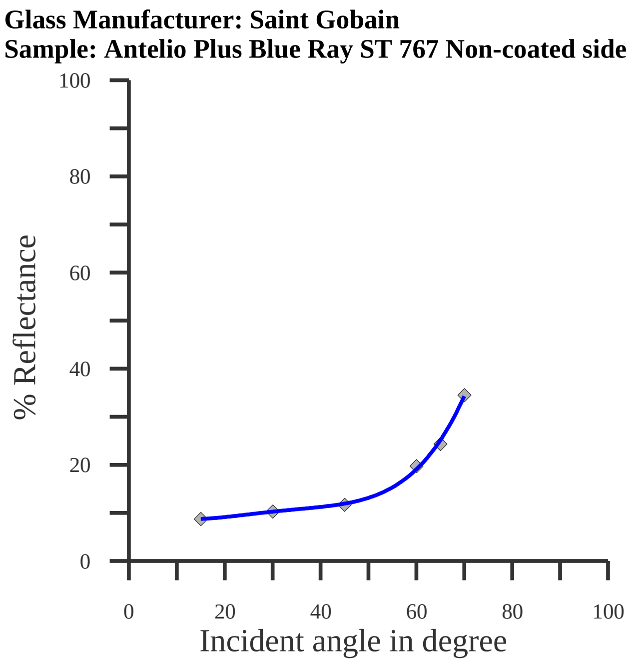


Fig 4.135: % Reflectance vs Incident angle in degree curve for non-coated side of sample ST 767

From Fig. 4.134 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.135 we can see that % reflectance curve remains almost same from 15^0 to 45^0 and then increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

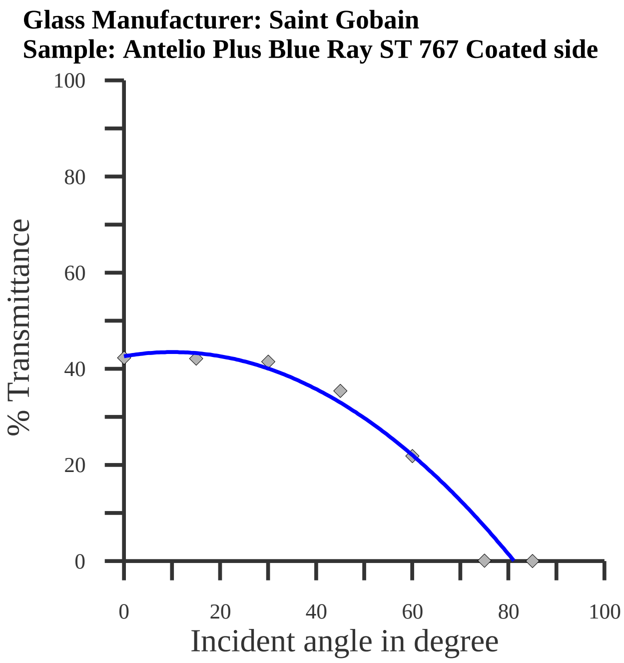


Fig 4.136: % Transmittance vs Incident angle in degree curve for coated side of sample ST 767

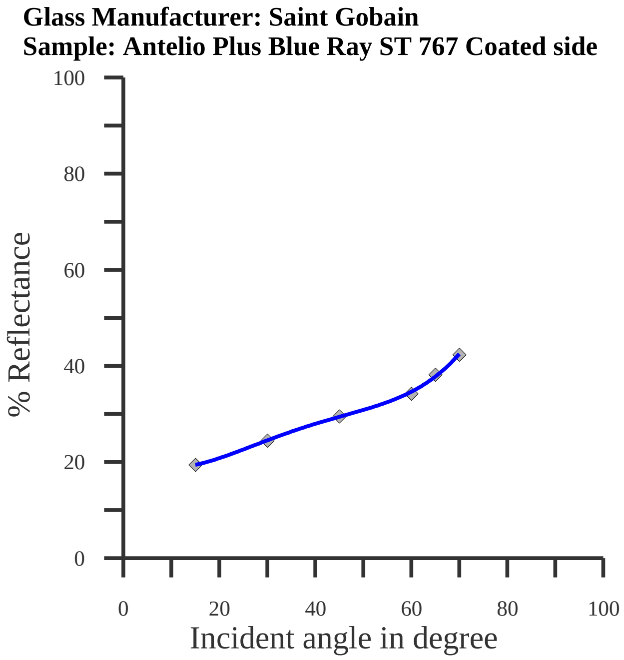


Fig 4.137: % Reflectance vs Incident angle in degree curve for coated side of sample ST 767

From Fig. 4.136 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.137 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.137 with Fig. 4.135. The reason could be coating which is present on one side of glazing sample.

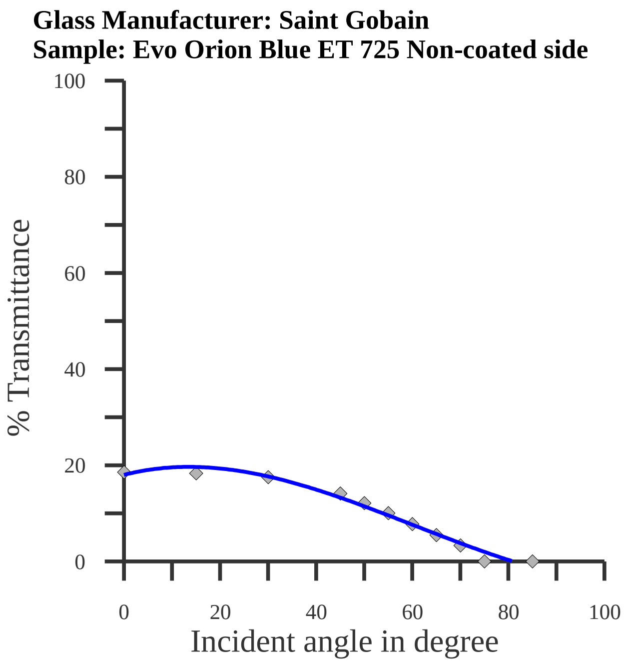


Fig 4.138: % Transmittance vs Incident angle in degree curve for non-coated side of sample ET 725

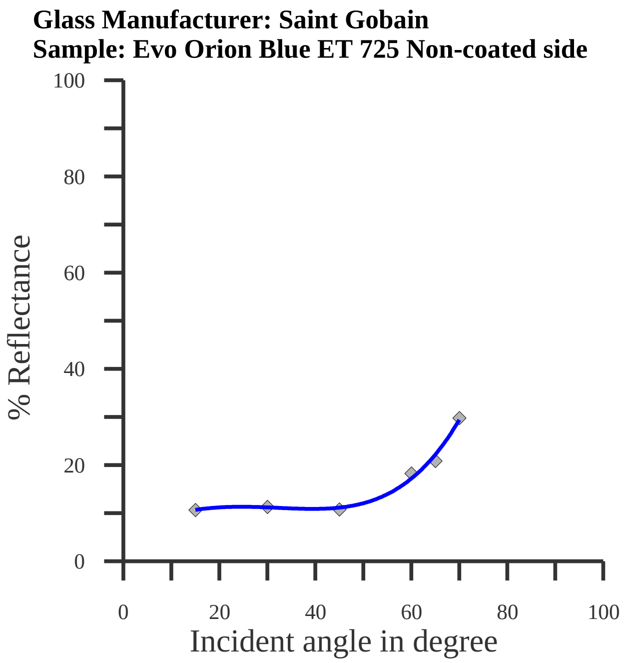


Fig 4.139: % Reflectance vs Incident angle in degree curve for non-coated side of sample ET 725

From Fig. 4.138 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.139 we can see that % reflectance curve remains almost same from 15^0 to 45^0 and then increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

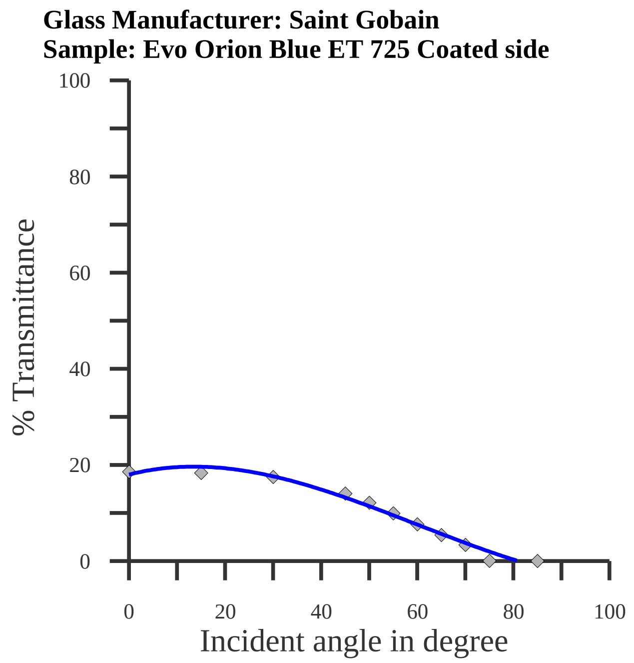


Fig 4.140: % Transmittance vs Incident angle in degree curve for coated side of sample ET 725

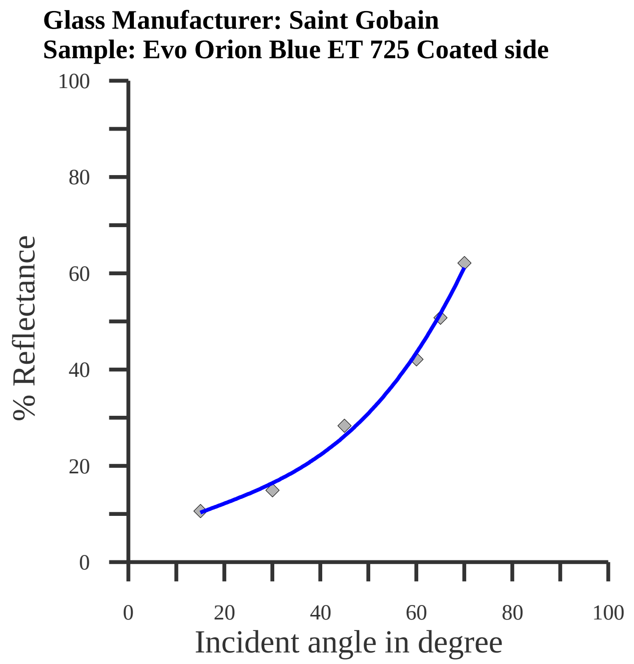


Fig 4.141: % Reflectance vs Incident angle in degree curve for coated side of sample ET 725

From Fig. 4.140 we can see that the % transmittance curve remains almost same for the incidence angle from 0^0 to 30^0 and then decreases with the increase of incidence angle and from Fig. 4.141 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.141 with Fig. 4.139. The reason could be coating which is present on one side of glazing sample.

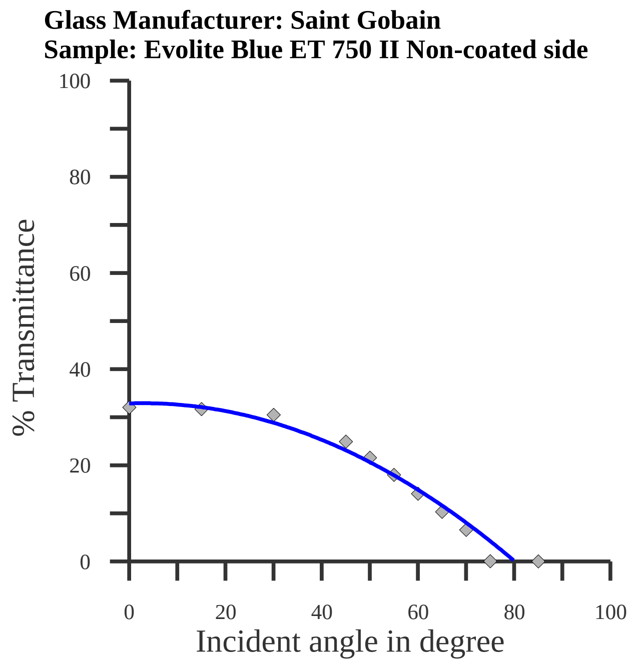


Fig 4.142: % Transmittance vs Incident angle in degree curve for non-coated side of sample ET 750 II

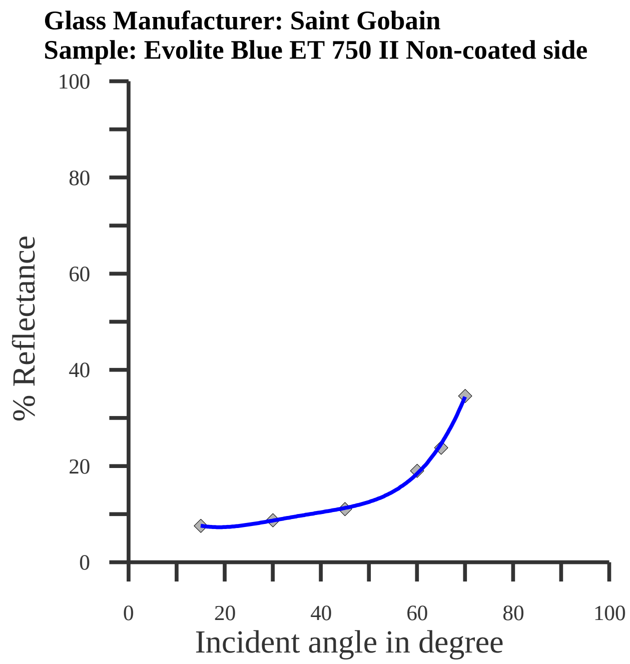


Fig 4.143: % Reflectance vs Incident angle in degree curve for non-coated side of sample ET 750 II

From Fig. 4.142 we can see that the % transmittance curve decreases with the increase of incidence angle and from Fig. 4.143 we can see that % reflectance curve increases with the increase of incidence angle from 15^0 to 70^0. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases.

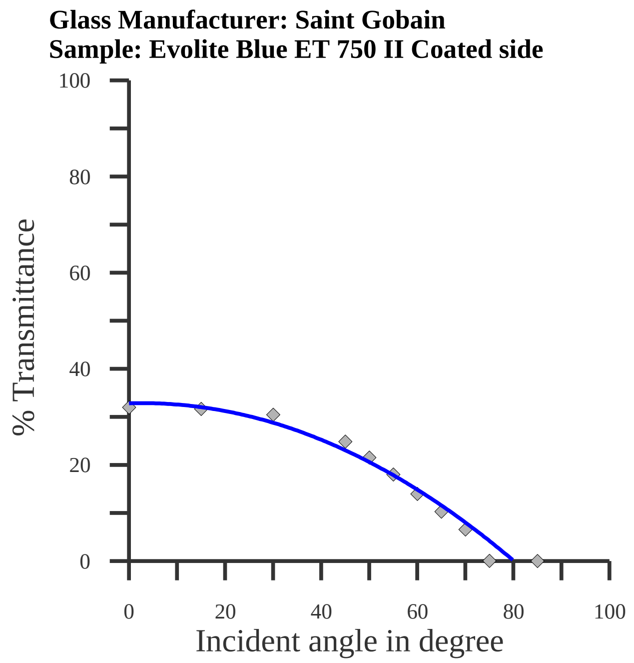


Fig 4.144: % Transmittance vs Incident angle in degree curve for coated side of sample ET 750 II

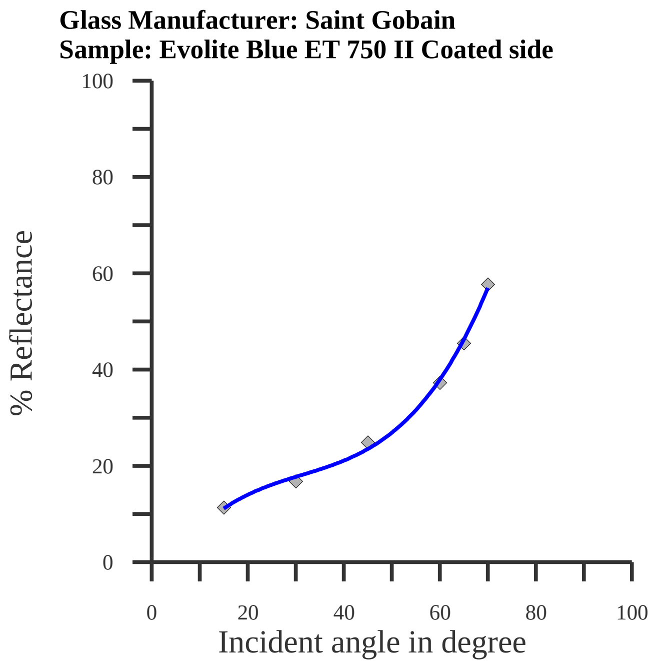


Fig 4.145: % Reflectance vs Incident angle in degree curve for coated side of sample ET 750 II

From Fig. 4.144 we can see that the % transmittance curve decreases with the increase of incidence angle and from Fig. 4.145 we can see that % reflectance increases with the increase of incidence angle. Thus by comparing both the figures we can say that with the increase in incident angle % transmittance decreases and % reflectance increases. The nature of curve is steeper when comparing Fig. 4.145 with Fig. 4.143. The reason could be coating which is present on one side of glazing sample.

Chapter 5: Computational Algorithm

5.1 Introduction

In this chapter we shall discuss about the calculation method to find out the solar optical properties from the measured spectral data of Perkin- Elmer Lambda-35 Spectrophotometer using British Standard (BS EN 410) [28] method. While Programming has been done using FORTRAN language (F-95) inorder to calculate the light transmittance (τ_v) and reflectance (p_v) from the spectral data and the graph is plotted which can be seen from Fig. 4.82 to Fig. 4.145.

5.2 Calculation of light transmittance (τ_v) and light reflectance (p_v)

The light transmittance (τ_v) and reflectance (p_v) from the spectral data of single glazing [28] is calculated by developing a program using FORTRAN language (F-95) and the formula for calculating light transmittance (τ_v) and reflectance (p_v) is given below:

- Formula for calculating light transmittance (τ_v)

$$\tau_V = \frac{\sum_{\lambda=380}^{\lambda=780} D_\lambda \, \tau(\lambda) V(\lambda) \Delta\lambda}{\sum_{\lambda=380}^{\lambda=780} D_\lambda V(\lambda) \Delta\lambda}$$

- Formula for calculating light reflectance (p_v)

$$p_V = \frac{\sum_{\lambda=380}^{\lambda=780} D_\lambda \, p(\lambda) V(\lambda) \Delta\lambda}{\sum_{\lambda=380}^{\lambda=780} D_\lambda V(\lambda) \Delta\lambda}$$

The optical absorbtance in the solar spectrum can be also computed knowing the transmittance and reflectance at any wavelength (λ) as

$$\alpha_\lambda = 1 - (\tau_\lambda + p_\lambda)$$

Various steps were taken for the calculation of light transmittance (τ_v) and reflectance (p_v) using program language for which flow diagram given in Fig.5.1 and Fig. 5.2 respectively.

a) For light transmittance (τ_v)

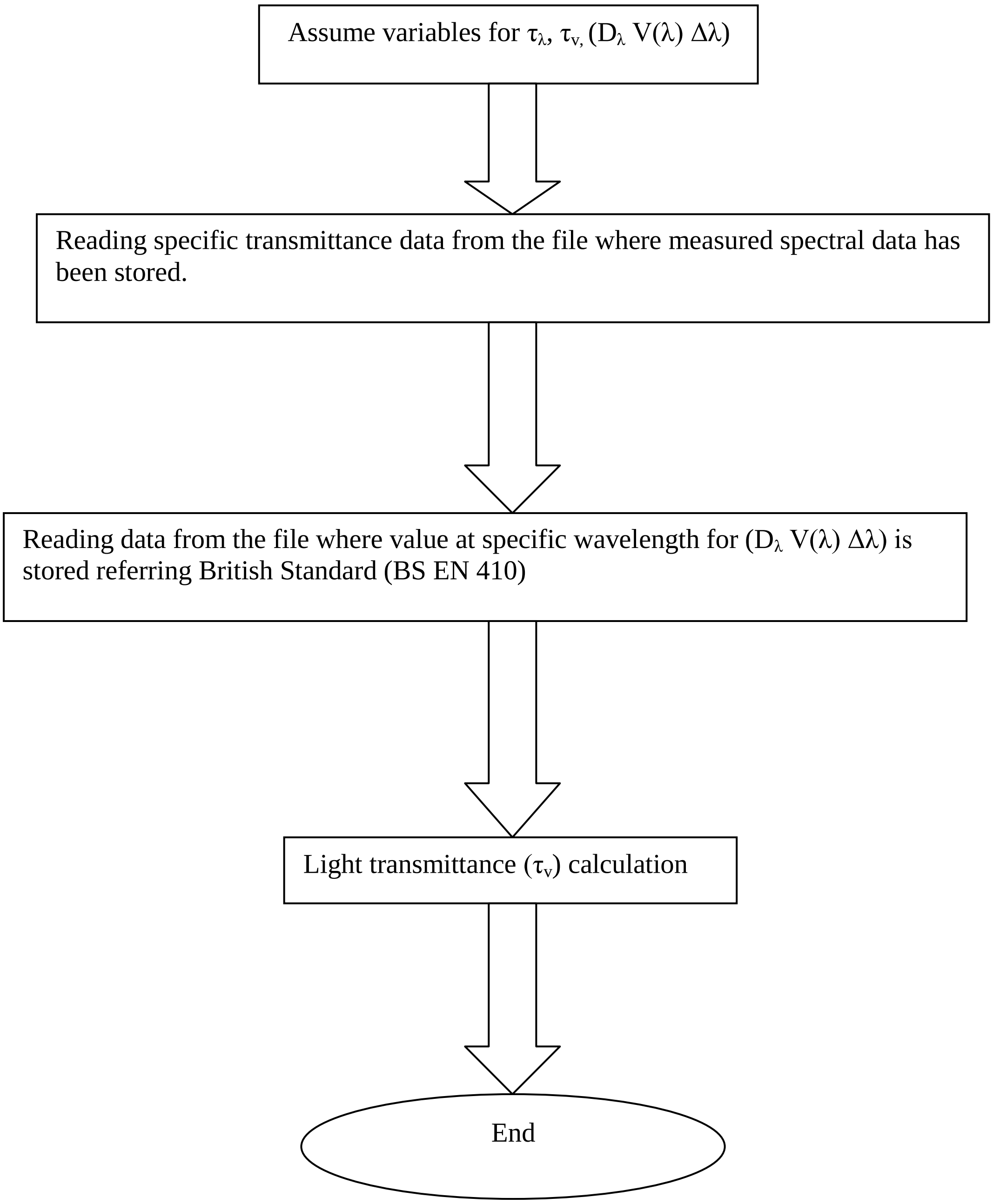


Fig. 5.1

b) For light reflectance (p_v)

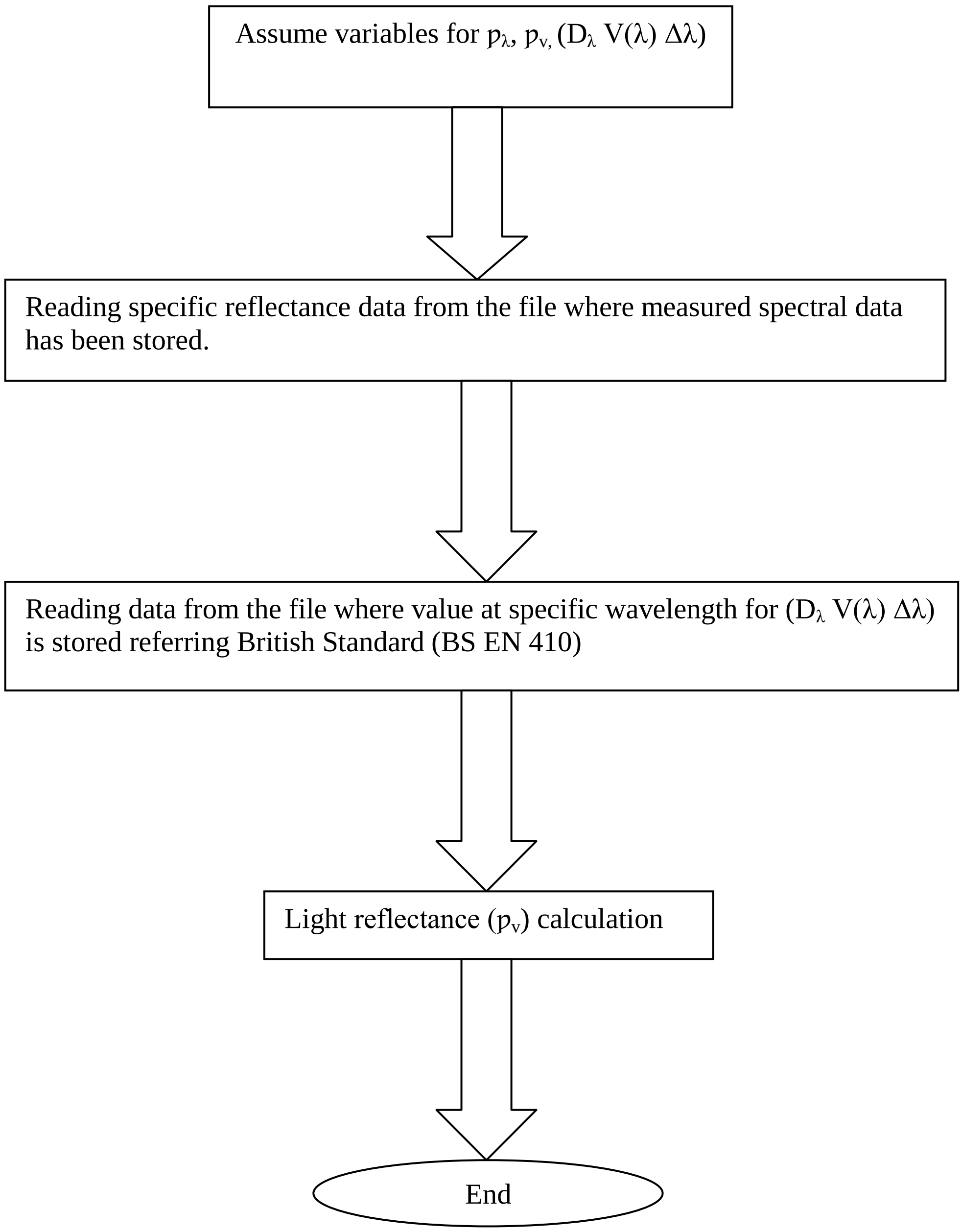


Fig. 5.2

Chapter 6: Conclusion

6.1 Conclusion

In our present study, we analyzed optical properties of various glazing samples and comparison of spectral transmittance and spectral reflectance were done at various angle of incidence of light using Perkin-Elmer lamda-35 spectrophotometer in UV – vis range.

Results showed that with the increase in the angle of incidence, transmittance remains almost same for the incidence angle of 0^0 to 30^0 and then decreases with the increase of incidence angle and in case of reflectance, with the increase in the angle of incidence reflectance also increases with some exceptions.

We evaluated the light transmittance and reflectance of various glazing samples from the measured spectral data obtained from Perkin-Elmer lamda-35 spectrophotometer in UV – vis range using British Standard (BS EN 410) with the help of a programming language (FORTRAN). The results showed that with the increase in incident angle % transmittance decreases and % reflectance increases.

In this study we also analyzed optical properties of some of glazing sample using Jasco V-770 Spectrophotometer in UV – vis – NIR range and compared this properties with that of results obtained by Perkin-Elmer lamda-35 spectrophotometer in UV – vis range. Moreover, the optical properties of glazing sample obtained in infrared region by Jasco V-770 Spectrophotometer could be used to assess the thermal performance of glazing material.

Researchers and engineers may find this study useful for designing windows of energy efficient buildings as glazing significantly contributes to the heat transfer between outdoor and indoor spaces, which act directly on daylighting and thermal comfort.

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