Chapter

Noise Transmission Losses in Integrated Acoustic and Thermo-Fluid Insulation Panels

Himanshu Dehra

Abstract

A simulation model is proposed for integrated acoustic and thermo-fluid insulation constituting an airflow window with a photovoltaic (PV) solar wall spandrel section. The physical model of an outdoor test-room comprises of a wooden framed double or cavity wall assembly with: (i) a triple glazed fenestration section with a closed roller blind; (ii) a solar wall spandrel section of double-glass PV modules and back panel of polystyrene filled plywood board; and (iii) fan pressure-based manually operated inlet and exhaust dampers with ventilation through an exhaust fan for transportation of heat. A generalized two-dimensional analysis of a double wall structure is illustrated by the placement of surface and air nodes into two adjacent stacks of control volumes representing outer and inner walls. The integrated noise insulation and energy conversion model is presented. The energy conversion and noise insulation model are supported with some numerical results using devised noise measurement equations. The following additional parameters are also calculated to support the integrated insulation model: noise transmission losses and noise reduction coefficients for various types of noises. State-of-the-art of acoustic and thermo-fluid insulation along with general building construction guidelines for acoustic and thermal insulation are also presented.

Keywords: integrated noise insulation, insulation materials, acoustic insulation, thermo-fluid insulation, solar energy

1. Introduction

The passage of air in and out—and heat along with it—is called infiltration. The significance of infiltration is clear from the fact that the average house has 600 cm^2 of vents and flues alone; plus window frames, doors, sills, and corners that need sealing and plugging; fireplaces with unfit dampers; and a front door that is slammed 3000 times a year. Air passes in and out through these openings. Therefore, infiltration is a misleading word—since it only denotes a one-way movement of air into a house. There is need of better word than breathing or respiration or exchange. Focusing entirely on insulation thickness, the best way to define all flow of air in and out through unsealed slits and unplugged holes is by huff and puff of a house. Due to a slit between the sash and the frame or the frame and the house, a 1.25×1.25 m^2 double glazed window will easily lose about 70 L of oil in winter, and some studies have suggested that windows account for even more heat loss than roofs. Double or triple panes are not the only solution. Traditionally, the most effective defense is solid, thermal shutters, put up from the inside that fit the window hole exactly.

This chapter attempts to bring up integrated noise insulation modeling for airflow windows along with their use as a sustainable energy source of electric and thermal energy besides providing daylighting. The airflow window system with photovoltaic modules embedded in solar wall spandrel as illustrated in **Figure 1** has been considered for investigations [1–60]. A triple glazed airflow window combined with a PV solar wall spandrel has many advantages: (i) airflow window provides electric power, hybrid ventilation through heating/cooling, daylighting and reduction in greenhouse gas emissions by energy conservation of fossil fuels; (ii) it provides integrated sound and thermal insulation; (iii) it gives protection from excessive heating from solar radiation by passing and controlling the amount of heat transport; (iv) it gives protection to PV modules from excessive heating, weather deterioration including protection from snow and dust; (v) with frame supporting structures, the system is easily approachable for repair and maintenance jobs; and (vi) it has better esthetic appearance to the occupants and to the viewers from outside in comparison with stand-alone PV module power generating system.

1.1 Physical model description

A full-scale experimental test section comprising an airflow window with a single pane exterior glazing and a double pane interior glazing and a photovoltaic solar wall spandrel was constructed in an outdoor room facility at Concordia University, Montréal, Québec [3–60]. The transportation of heat was achieved through manually operated intake and set of exhaust dampers. The intake and exhaust dampers located on exterior side were fitted with wire mesh screens. The exhaust damper placed on the interior side toward outdoor room is for allowing the pre-conditioned outdoor air directly into the room indoor environment. The air movement in the airflow window system was achieved through: (i) buoyancy-induced hybrid flow and (ii) fan-assisted flow created either in absence or presence of wind-induced flow.

In airflow window integrated with PV module, there are many issues related to its operation. The main objective is to model the integrated thermal and sound

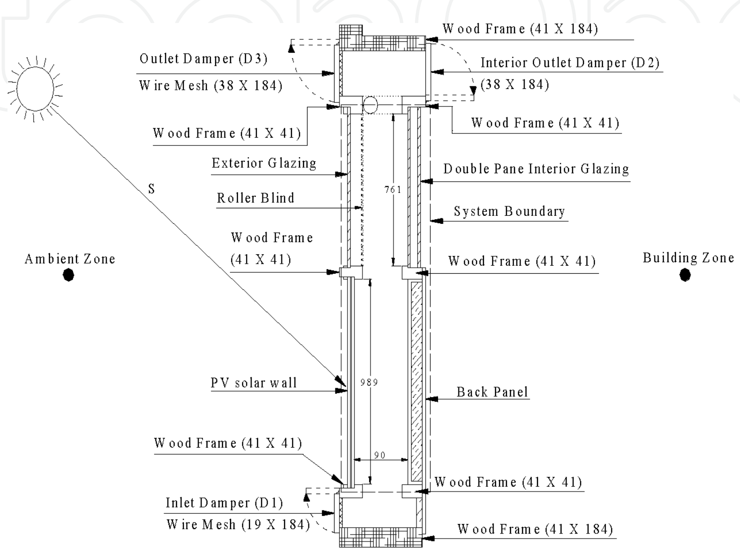

Figure 1.
Schematic of an airflow window system with a PV solar wall spandrel section (dimensions provided are in mm).

insulation fields and to maximize the value of total energy generated and therefore increase the combined efficiency of the system. In achieving this objective, the heat transfer model and losses of PV model need to be studied. The heat can be recovered from the heated PV modules in different ways. One of the options is to treat the heated PV module as absorber surface and pass airflow through the surface. The key operation parameters are air mass flow rate, area of the absorber surface (PV, Blind) and its temperature. Air mass flow rate requires optimum air velocity under various conditions to prevent condensation, stagnant zones, flow reversal and other adverse effects that will cause deterioration of the PV panels. This optimization of airflow will maximize the absorbed solar radiation conversion to either thermal or electric power. By placing motorized blind after the integrated PV, will achieve twin objectives, control the amount of daylight transmission and also help in absorbing the excess external heat, which is going inside the room and overheating it. This heat is further taken from blind by mass flow of air, while cooling the PV modules. Depending on the climatic variables the operation of airflow window can be optimized. Damper motion is controlled by both flow and temperature sensors. During the summer, in the daytime, when outside air temperature is in the range of 15–22°C, the exhaust air vent provided will exhaust the heated air from PV modules to outside. But during night, the cooled fresh air can be used inside the room to reduce the cooling load of the building. Another important aspect is to control the amount of daylight transmission by optimizing sizing and distribution of opaque photovoltaic modules for maximizing the value of thermal and electric power generated.

2. State-of-the-art

Traditionally, insulation is dead air space, or a dead gas space, sometimes combined with a reflective surface. Air has a low inherent conductivity. If it is dead or motionless there is no convection and when there is a reflective surface, radiation is cut to a minimum. Dead air space can be found in materials like fiberglass blanket, loose-fill and foam. They embody thousands of tiny pockets where dead air is encased, protected and preserved.

Outdoor duct system consists of combination of fans, duct construction elements, heat exchangers and air filters. The location of fan in outdoor duct is decided by the direction of flow and desired pressure relations. A supply fan is used to pump air into a space and exhaust fan is used to draw air out of a space. The pressure relations for the two cases are different. There is a buildup pressure in case of supply air and reduction of pressure in case of exhaust air. The space pressure is determined based on the relative quantity of air handled by supply and exhaust air. The space pressure will be positive if there is an excess supply air in comparison to exhaust air and negative if there is an excess exhaust air in comparison to supply air.

The total energy provided by the fans to the air passing through a given system is fixed, assuming the same capacities and end pressures for a supply fan, an exhaust fan or both are used. A motor-driven fan is used to circulate filtered heated air from outdoor duct through supply duct to outdoor test-room. As the hot air is delivered through the ducts and into the room through the supply outlet, cooler air from the room is being returned through return grilles, into the exhaust air duct.

The choice of fan is dependent on creating a sufficient pressure is achieved to overcome the total losses based on the flow through the duct with longest run. Fan performance must meet and match system requirements. The only possible operating characteristic points are those where the system curve intersects the fan curve. These are the points where the pressure developed by the fan exactly matches the system resistance, and the flow in the duct system equals the fan capacity. The overall system resistance is calculated by summing the pressure losses for the individual components along any one flow path.

Air passing through the outdoor duct system is either heated or cooled. It results in decreased or increased density, respectively, and with assumption of constant mass flow rate, its total volume rate will be increased or decreased accordingly. The developed resistance in the duct is calculated based on actual gas density, volume, and velocity through it. The total system resistance is calculated by summation of these resistances along the flow path.

The difference in power requirements at various locations can be calculated. For the case of constant system resistance, the pressure required for the fan (P2 – P1) will be constant regardless of the location. The volume of air flow (Q) will vary with the location. The fan location with least power requirements is that place where density of air will be highest assuming constant efficiency.

Exterior duct insulation can be attached with adhesive, with supplemental pre-attached pins and clips, with wiring or bands. Liners can be attached with adhesive and supplemental pins/clips. Rectangular ducts and fittings are fabricated by grooving, folding, and taping with metal accessories such as turning vanes, splitters, and dampers incorporated into the system. If rectangular ducts exceed the pre-determined dimensions for particular static pressure, the ductwork must be reinforced. Insulation can significantly reduce operating costs that depend upon unit cost of heating and cooling energy, extent of duct exposed to outside conditions. In addition, duct insulation maintains the supply air temperature unaltered thereby, maintaining the conditioned space within acceptable temperature range. Vapor retarders are required on exterior insulation of ducts that are used for alternate heating and cooling.

Some thermal insulation materials can also serve purpose of sound control [1]. Acoustic efficiency depends upon physical structure of the material. Materials with open, porous surfaces have sound absorption capability [2]. Those with high density and resilient character can be used for absorption of vibrations. Insulation for sound conditioning includes flexible and semi-rigid, formed-in-place fibrous materials and rigid fibrous insulation. Thermal insulation materials improve their sound insulation when installed with discontinuous construction. A wall of staggered stud construction that uses resilient clips or channels on one side of the stud or resilient boards of special manufacture to prevent acoustic coupling mechanically between the surfaces, reduces sound transmission. Sound absorption by thermal insulation blanket in a cavity wall reduces sound transmission.

The energy conversion and noise characterization in an exterior double wall is important, for example, in modeling PV solar wall and transpired unglazed structures [1–60]. The energy conversion in a double of cavity wall is a function of solar irradiation, air gap width, mass flow rate and pressure, wall and air temperatures. A generalized two dimensional thermal analysis of an outdoor duct is presented by placement of surface and air nodes into two adjacent stacks of control volumes representing outer and inner walls of duct. A matrix solution procedure is adopted by constituting conjugate heat exchange of conduction, convection, radiation and ventilation heat transport.

The requisite amount of ventilation air in a building in a given climate depends on heating/cooling load. The HVAC load on building varies with the condition of outdoor ventilation air that may require additional heating, cooling and humidification or dehumidification. In temperate climates, outdoor air is more economical to use than recycled return air. The analysis of double or cavity wall for ventilation purposes using airflow window with PV solar wall structures is investigated. The investigation of energy conversion, ventilation and integrated insulation system is based on complete information for the given design conditions and limitations of operation results.

2.1 Absorption of sound

When a sound wave strikes a surface, part of its energy is absorbed by friction, part of its energy is transmitted, and the remaining part of its energy is reflected. But as reverberation directly depends on the loss of energy of sound wave due to friction, it is of greater importance. This property of a surface by which sound energy is converted into other form of energy is known as absorption and absorption coefficient of a surface indicates the degree to which this surface affects the absorption of sound. It is thus the ratio of energy absorbed by the area to the energy striking the area. The value of coefficient of absorption will depend on the frequency of sound. **Table 1** gives the value of coefficients of absorption for some common surfaces. These values correspond to the normal frequency of 500 cycles per second. It may be noted that coefficient of absorption for an open window is taken as unity. This is very easy to understand as sound wave approaching an open window must completely pass through it.

Sound absorbent materials: most of the common building materials absorb sound to a small extent and hence, for better acoustical requirement, some other materials are to be incorporated on the surfaces of the room. Such materials are known as absorbent materials and they help a great deal in making the room acoustically good. The important characteristics of absorbent materials are:

1. An ideal absorbent material should be economical in construction and maintenance, waterproof, fire-proof, sufficiently strong and good in appearance.

2. Noise level of the room provided with absorbent materials is considerably reduced.

3. In the hall treated with absorbent materials, speech can be heard clearly, and music can be fully enjoyed.

4. All the absorbent materials are found to be soft and porous. They work on the principle that sound waves penetrate into the pores, and in this process, sound waves are converted into other form of energy by friction.

5. The absorbing capacity of the absorbent materials depends on the thickness of the material, its density and frequency of sound.

6. The sound properties of the absorbent materials are considerably changed by their modes of fixing. Suspended absorbers in the form of inverted cones may be provided in the ceiling to make the hall acoustically sound good.

7. There is no royal road for making a particular room acoustically good. It mainly depends on the ideas of the technical staff either engineer or architect. Each case is to be studied separately and after proper thinking, suitable absorbent materials may be specified.

8. Great care should be exercised while prescribing the covering for an absorbent material so as to improve its appearance. Improper covering destroys the absorbent properties of the material.

Material	Absorption coefficient per m^2
Open window	1.00
Ventilators	0.10 to 0.50
Brick wall 40 cm thick	0.03
Plaster on wall surface	0.02
Glass against solid surface	0.03
Marble	0.01
Stage curtain	0.20
Linoleum or concrete floor	0.03
Solid wooden floor	0.09
Framed wooden floor	0.13
Plywood on battens	0.17 to 0.26
Window glazed	0.18
Curtains in heavy folds	0.40 to 0.75
Metal	0.01

Table 1.
Absorption coefficients.

9. It should be remembered that in a big hall, audience is a major absorbing factor. This is especially true in the high frequency zone. Hence, low frequency absorbent materials should be provided to achieve optimum reverberation time over a wide range of frequency of sound.

2.1.1 Types of absorbent materials

Various types of absorbent materials are available in the market under different trade names. The value of coefficient of absorption is supplied by the manufacturer. The choice of the absorbent material should be made after carefully considering various factors such as appearance, cost, workability, flame resistance, durability, and light reflection. Following are some of the common types of absorbent materials:

1. Hairfelt: the average value of coefficient of absorption for Hairfelt for 25 mm thickness is 0.60.

2. Acoustic plaster: this is also known as fibrous plaster and it includes granulated insulation material mixed with cement. If quantity of cement is more than required, the plaster will not have sufficient pores to become effective for acoustics. If quantity of cement is less, the plaster will not have enough strength. Thus the quantity of cement should be carefully decided. For thickness of 20 mm and density of 0.10 g per cm^3, the acoustic plaster possesses an absorbent coefficient of 0.30 at 500 cycles per second. Acoustic plaster boards are also available. They can be fixed on the wall and their coefficient of absorption varies from 0.15 to 0.30.

3. Acoustical tiles: these are made in factory and sold under different trade names. The absorption of sound is uniform from tile to tile and they can be fixed easily. However, acoustical tiles are relatively costly than other absorbent

materials. They are most suitable for rooms in which small area is available for acoustical treatment.

4. Strawboard: this material can be used as absorbent material. With a thickness of 13 mm and density of 0.24 g per cm^3, it possesses a coefficient of absorption of 0.30 at 500 cycles per second.

5. Pulp boards: these are soft boards which are prepared from compressed pulp. They are not expensive and can be fixed by ordinary paneling. The average value of coefficient of absorption is 0.17.

6. Compressed fiberboard: this material may be perforated or unperforated. The average coefficient of absorption for perforated board is 0.30 and for the unperforated board is 0.52. It has a density of 0.30 g per cm^3.

7. Compressed wood particle board: this material is provided with perforations and it can be painted also. With a thickness of about 13 mm, the average coefficient of absorption is 0.40.

8. Perforated plywood: this material can be used by forming composite panels with mineral wool and hardboard. It is generally suspended from trusses. The average value of coefficient of absorption for the former composite panel is about 0.20.

9. Wood wool board: this material is generally used with a thickness of 25 mm and it has a density of 0.40 g per cm^3. The average value of coefficient of absorption is 0.20.

10. Quilts and mats: these are prepared from mineral wool or glass wool and are fixed in the form of acoustic blankets. The absorption coefficients of such quilts and mats depend on the thickness, density, perforations, mode of fixing, nature of backing and frequency of sound.

2.2 Noise and its effects

When the sound waves are non-periodic, irregular and of short duration, they produce a displeasing effect and such a sound is known as noise. Thus a noise is an unwanted abrupt sound of complex character with an irregular period and amplitude originating from a source of non-periodic motion.

Following are the important effects of noise: (i) noise creates uncomfortable living conditions; (ii) prolonged exposure to noise may result into temporary deafness or nervous breakdowns; (iii) it is observed that noise has an influence on blood pressure, on muscular strain and even on sleep; (iv) noise leads to fatigue and consequently, the efficiency of persons exposed to noise decreases considerably; (v) it is an established fact that reduction in noise increases to a great extent the output of labor; (vi) presence of noise takes away the essence of music and speech.

2.2.1 Transmission of noise

Any type of noise is transmitted to the room through walls, floors, ceilings or conduits. The origin of transmitted noise may be air-borne or may be due to impact.

Air-borne noise can be transmitted to the receiving room in two ways: (i) by air path between two rooms such as doors, windows, ventilators, key holes, ducts, pipes, and cracks and (ii) by forced vibrations set up by the transmitting room to the walls, floors and ceiling of the receiving room. It is found that air-borne noise sets up forced vibrations in the walls, floors and ceiling of the transmitting room and they in turn set up corresponding vibrations in the walls, floors and ceiling of the receiving room. These surfaces of the receiving room create sound waves and noise is thus transmitted to the receiving room.

Impact noise or structure-borne noise is developed in solid structures and it is then transmitted as air-borne noise. Closing of doors, vibrations of machines, etc., set up vibrations in solid materials of the structure which result in transmission of noise to the receiving room.

Air-borne noise possesses less power, continues for a long duration and is confined to places near its origin. Impact or structure-borne noise possesses more power, continues for a short duration and is often propagated over long distances.

2.3 Integrated sound and thermal insulation

Because some of thermal insulating materials have cellular or open matrix construction, they have inherent ability to absorb sound and act as panel dampers. They also reduce noise breakout, from the machinery plant by their ability to be flexible or discontinuous link between an acoustically active surface and the outer cladding. It should be remembered that sound insulation and sound absorption are quite different terms. The function of a sound insulating construction is to reduce sound passing through it. The function of a sound absorbent material is to reduce sound reflected from a surface. Hence, porous materials in general are good sound absorbers. But they are poor sound insulators. On the other hand, hard materials in general are poor sound absorbers. But they are good sound insulators. Further, insulation of sound is measured in an adjoining room while absorption of sound is measured in the room where sound is produced. The simple material which can be used as insulator is a sheet of material placed in the sound transmission pathways. Sound energy reaches the surface in the form of a pressure wave, of which partial energy passes through the partition and the rest is reflected.

Transmission loss: as the air-borne sound passes through any structure, loss of sound-intensity takes place. This is known as transmission loss.

Important facts: (i) transmission loss is numerically equal to the loss of intensity of noise; (ii) the efficiency of sound and thermo-fluid insulation of a wall or a partition is expressed in terms of transmission loss which occurs when air-borne physical agent passes through the wall or the partition; (iii) transmission loss varies directly with the frequency of physical agent. Hence, transmission loss of a structure should be studied over a wide range of frequencies. (iv) Greater insulation of a wall or a partition is indicated by the larger value of transmission loss.

Methods of sound insulation: the method of sound insulation will depend on the type of noise to be treated and the degree of sound insulation required. The methods of sound insulation can thus be classified in three main categories:

1. When source of noise is in the room itself: following are the methods of sound insulation which are commonly used when the source of noise is situated in the room to be treated for sound insulation:

    a. Improvement in working methods: the basic principle of sound insulation is to suppress the noise at the source itself. A working method creating less noise may be adopted. For instance, the machine in the room is enclosed in a box-like structure with sound absorbing on its surfaces.

b. Acoustical treatment: the walls, floors and ceilings should be provided with sound absorbing materials. The sound absorbing materials should be mounted on the surfaces near the source of noise. The acoustical treatment of the room considerably reduces the noise level in the room.

c. Personal protective devices: it is possible to reduce the noise to some extent by using personal protective devices such as ear plugs and headphones.

2. When noise is air-borne: the sounds generated and transmitted in air directly to human ears are known as air-borne sounds. The air-borne noise possesses less power, continues for a long duration and is confined to places near its origin. Following methods of sound insulation may be adopted for the reduction of air-borne noise:

a. Solid non-porous homogeneous partitions: provision of solid non-porous homogeneous partitions will reduce air-borne noise. It is found that transmission loss of such partitions depends directly on the weight of partition per unit area. The sound insulation of a partition thus increases with the increase in its thickness. But doubling the thickness of a partition reduces transmission loss by a constant amount. This figure is practically constant and can be used to work out the transmission loss of the partition with different thicknesses. It can thus be seen that sound insulation by solid non-porous homogeneous partitions is expensive in quantity of material.

b. Partitions of porous materials: the porous materials may be rigid or flexible. For partitions of rigid porous materials such as concrete masonry, the sound insulation increases about 10% due to the absorptive property of the material. But partitions of flexible porous materials such as wool and quilt do not give enough sound insulation. However, the value of transmission loss decreases as further layers of flexible porous materials are added. The general behavior of partitions of flexible porous materials is such that as the thickness of partition is increased in arithmetic progression, the corresponding transmission loss is in geometric progression. A combination of rigid porous materials and flexible porous materials may be used with advantage for the construction of partition wall. It will provide effective sound insulation and will have less weight.

c. Double wall construction: it is found that a double wall construction is better for sound insulation than a solid wall construction. The walls are of plasterboards or fiberboards or plaster on lath. An air space of about 10 to 12 cm is kept between the walls and staggered wooden studs are provided. In order to make the partition more effective, it is necessary to reduce the number of structural ties between the two parts of the partition to a minimum. The hollow space may be filled with sound absorbing blankets.

d. Floating floor construction: in this type of construction, a floor is separated from the structural floor by means of a layer of resilient material such as mineral and glass wool quilt. Such a floor is known as a floating floor and it results in better sound insulation.

e. Suspended ceiling construction: if a false independent ceiling is constructed below the structural floor, the sound insulation capacity of the floor increases. This construction is useful especially in case of wood-joist floors.

f. Box-type construction: this type of construction gives exceptionally low value of air-borne transmission and hence, it is adopted at places such as broadcasting studios where low air-borne sound transmission is most essential. A box-like structure is construction on the structural floor.

g. Design of doors and windows: for good insulation, it is necessary to design carefully the doors and windows of the room. The sound travels through very thin cracks between the door and wall. The space between the jamb and frame may be packed with sound absorbing material. In case of a door, the transmission loss increases with the increase in weight. In case of a window, the transmission loss increases with increase in thickness of glass. Excellent sound insulation is obtained by constructing glazed windows with double or triple panes of glass. The air space at the edges of such panes is filled with sound absorbing material.

h. Planning of rooms: if rooms within residential buildings are suitably arranged, good sound insulation is achieved. It is also economical than structural measures required for good sound insulation.

3. When noise is structure-borne: the sounds which originate and progress on the building structure are known as structure-borne sounds or impact sounds. The structure-borne noise is powerful, propagates over long distances and persists for a very short duration. Following methods of sound insulation may be adopted for the reduction of structure-borne noise:

a. Treatment of floors and ceilings: the floors and ceilings may be treated for floating floors and suspended ceilings which help in considerably reducing structure-bore sound.

b. Discontinuous construction: this method is similar to box-type construction. The walls of the rooms are constructed on floating floors and the ceilings of the rooms are suspended from the structural floors. The use of structural ties with the main walls is avoided as far as possible or special resilient isolators are employed for this purpose.

c. Insulation of machinery: mechanical equipment such as refrigerators, lifts, and fans create vibrations in the structure and hence, if they are isolated properly, structure-borne sound is reduced to a considerable extent. The main principle of insulation of machinery is to rest the mechanical equipment on a flexible support which may be of rubber, cork, felt or metal spring.

d. Town planning: vibrations from external sources such as railways, metros, cars, traffic, and factories create structure-borne sound. The most effective method for reducing such type of structure-borne sound is to have a rational town planning. The city is divided into suitable zones and residential zone is placed away from railways, workshops, factories and main streets.

2.4 Thermal insulation definition

The temperatures inside and outside a building are different. Some building materials allow heat to pass rapidly while others do not allow passage of heat smoothly. The term thermal resistance is used to indicate the construction by which transmission of heat from or in the room is retarded. The main aim of thermal insulation is to minimize the transfer of heat between outside and inside of the building.

Advantages of thermal insulation: the advantages derived from thermal insulation are as follows: (i) comfort: due to thermal insulation, the room remains cool in summer and warm in winter than outside. Hence, a room provided with thermal insulation gives comfort both in summer and winter. (ii) Fuel saving: due to thermal insulation, transfer of heat from inside to outside of the room is reduced. This results in less quantity of fuel required to maintain the desired temperature in the room. (iii) Condensation: the provision of thermal insulating materials inside a room prevents condensation on interior walls and ceilings. Condensation is the deposition of moisture and it takes place when warm air comes into contact with surfaces having temperature below the dew point. (iv) Water system: the use of thermal insulating materials prevents the freezing of water taps in extreme winter and heat loss in case of hot water system.

General principles: following are the general principles of thermal insulation: (i) the thermal resistance of an insulating material is directly proportional to its thickness. (ii) Provision of an air gap is a very important insulating agent and is very essential. (iii) The thermal resistance of a building depends on its orientation also. The building should be so located that there is maximum transfer of solar energy in winter and there is minimum transfer of solar energy in summer.

Insulating materials: the choice of an insulating material depends on the cost, area to be covered, standard of insulation required and the cost of heating or cooling. The thermal insulating material should be reasonably fire-proof, non-absorbent of moisture, able to resist attack on small insects and not liable to undergo deformation. The usual insulating materials are rockwool, slag wool, fiberboards, flexible blankets, saw dust, wood-shavings, cork board slabs, mineral wool slabs, aluminum foils, products of cement concrete with lightweight aggregates, gypsum board, chip board, gasket cork sheet, foam plastic, etc.

Table 2 shows the density, thermal conductivity and thermal resistivity of some of the common building and insulating materials. In general, it may be stated that the materials of low density provide better thermal insulation than those of higher density.

2.4.1 Thermal insulation of exposed doors and windows

Doors and windows which are exposed transmit heat to a considerable extent. Following methods may be employed to ensure heat insulation of exposed doors and windows: (i) insulating glass or double glass with air space may be provided for glazed doors and windows. This will reduce heat transmission through doors and windows. (ii) In order to reduce incidence of solar heat, projections in the form of sun breakers, weather-sheds, projections, curtains, venetian blinds, etc. may be provided on the exposed doors and windows.

2.4.2 Thermal insulation of exposed roofs

Thermal insulation of exposed roofs may be achieved by treating inside surface or outside surface.

Internal treatment: (i) false ceiling with an air gap may be provided. The ceiling is made of thermal insulating materials. (ii) Light insulating materials may be pasted by suitable adhesives to the inside surfaces of the exposed roofs.

External treatment: (i) suitable shade may be provided on the exposed roof surfaces. (ii) Shinning and reflecting materials may be fixed on the top of exposed roofs. (iii) For flat roofs, an air space may be created by arranging

No.	Material	Density (kg/ m^3)	Thermal conductivity K (kcal/m h °C)	Thermal resistivity (1/K)
1	Artificial stone	1760	1.14	0.88
2	Asbestos cement sheet	1520	0.25	4.00
3	Asphalt	2240	1.05	0.95
4	Cement concrete (1:2:4)	2240 to 2480	1.24	0.80
5	Compressed straw slab	368	0.074	13.51
6	Fiberboard	240 to 400	0.046 to 0.056	21.74 to 17.86
7	Glass	2510	0.905	1.10
8	Glass cellular	168	0.061	16.40
9	Glass fiber	48	0.029	34.50
10	Granite	2640	2.52	0.40
11	Hair felt	80	0.034	29.40
12	Limestone	2180	1.32	0.76
13	Ordinary bricks	1760	0.7 to 1.44	1.43 to 0.70
14	Plastering	1280 to 1600	0.50	2.00
15	Sand-lime bricks	1840	0.93	1.07
16	Sandstone	2000	1.12	0.90
17	Saw dust	192	0.051	19.60
18	Terrazzo	2430	1.363	0.73
19	Timber	480 to 270	0.124	8.00
20	Wood-wool slab	400	0.071	14.08

Table 2.
Density, thermal conductivity and thermal resistivity of some common building and insulating materials.

cement sheets or corrugated galvanized iron sheets on bricks. (iv) Flat roofs may be kept cool by water which may either be stored or sprayed at regular intervals. The surface temperature of the roof is reduced by this method. (v) Thermal insulation of flat roof may also be provided by putting a layer of about 25 mm thickness of coconut pith cement concrete. For this purpose, coconut pith and cement are mixed in dry state and then the mix is transferred to concrete mixer. Water in required quantity is added so as to obtain concrete of workable consistency. It is then conveyed and laid in suitable thickness on the roof. Wet coconut pith may also be used with due care and hard mixing may be adopted for small quantity of work. To avoid loss of water from concrete surface, it is covered by an impermeable layer and then it is allowed to dry in air for a period of 20 days to 1 month. Any cracks which are seen during drying period are filled up by the pith concrete. When the pith concrete layer has fully dried, water-proofing treatment may be given in the usual manner.

2.4.3 Thermal insulation of exposed walls

Following methods may be adopted for thermal insulation of exposed walls: (i) suitable thickness of wall may be provided. (ii) Hollow wall or cavity wall construction may be adopted. (iii) For partitions, an air space may be created by fixing hard boards on battens. (iv) The inside and outside surfaces of exposed wall may be provided with thermal insulating materials in such a way that the value of overall thermal transmittance is brought within desired limit. (v) If it is structurally suitable, the exposed wall may be constructed of thermal insulating materials. (vi) It is found that the application of light-colored whitewash or distemper on the exposed side of the wall will grant substantial thermal insulation.

3. Model assumptions and development

The assumptions used in the development of the model for a building integrated photovoltaic airflow window (BIPV-AW) system as depicted in **Figure 1** are: (i) fully developed heat transfer has been assumed for mixed convection heat transfer assuming a parallel plate wide channel at low air velocities ~0.5 m/s; (ii) temperature variation only along y-axis with lumped temperature distribution along x and z-axes; (iii) applicability of first law of thermodynamics at the surface; (iv) clear sky is applicable; (v) quasi steady state heat transfer analysis has been performed assuming a vertical channel; (vi) uniform average air velocity distribution; (vii) temperature variation only in y-direction (vertical), being taken as lumped in other directions (x-axis and z-axis); (viii) air properties are evaluated at film temperature of 300 K; (ix) negligible heat transfer from side walls/insulation panel and room air zone; (x) conduction (diffusion) equation for performing energy balance on air nodes is not taken into consideration; (xi) negligible thermal storage capacity of duct wall; (xii) no infiltration or air leakage sources from the test section; and (xiii) ambient air and room air temperatures are specified.

The system is discretized into network of two adjacent stacks of control volumes common to surface and air nodes (see **Figure 2**). The energy balances are performed on both surface and air nodes with aid of constitutive relations for noise fields due to solar intensity, sound intensity, airflow power intensity, electric power intensity and heat power intensity. The energy conversion and noise characterization is important, for example, in modeling airflow window and PV solar wall building structures. The resultant noise field due to composite wave elements (of heat, fluid, electricity, sound and sun) is a function of solar irradiation, sound intensity, air gap width, mass flow rate and pressure, wall and air temperatures of the double wall building structure. The integrated noise insulation due to thermal and sound

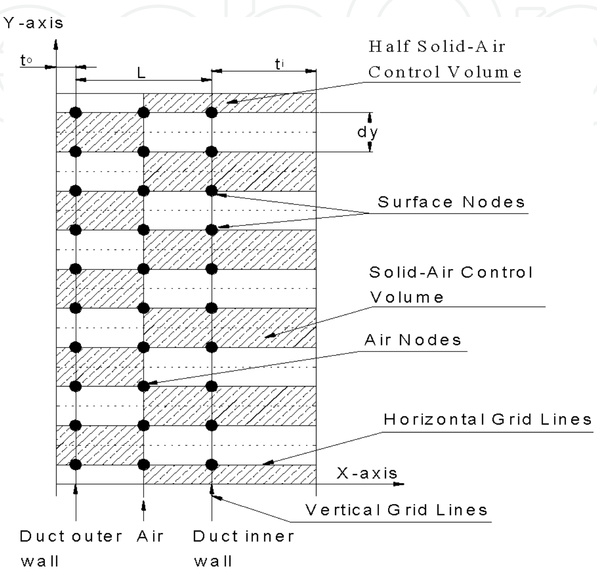

Figure 2.
Grid size in the duct: distribution of nodes and control volumes.

fields is modeled. Noise characterization equations are devised, which calculate noise fields due to ventilation, heat transport and sound transmission of integrated building insulation through a double wall structure.

In writing nodal equations in matrix form, sign notation is adopted for automatic formulation of conductance matrix (U-matrix) with unknown temperatures and heat source elements. The sum of all incoming heat source elements and U-matrix conductances multiplied with temperature difference with respect to the unknown temperatures at other nodes are equal to zero. The energy balance is written in equation form for any general node (m,n):

$$\sum_{n=1}^{N}\left(U_{m,n} \times \Delta T_{m,n}\right) + \sum_{n=1}^{N} Q_{m,n} = 0 \tag{1}$$

where $U_{m,n}$ is the conductance at node (m,n), $\Delta T_{m,n}$ is the difference between unknown temperature at the node (m,n) and unknown temperature at surrounding heat exchange node. $Q_{m,n}$ is heat source term at the node (m,n).

3.1 Noise characterization

A unified theory for stresses and oscillations is proposed by Dehra [12]. The following standard measurement equations are derived and adopted from the standard definitions for sources of noise interference [1–60].

Noise of sol: for a pack of solar energy wave, the multiplication of solar power storage and the velocity of light gives solar power intensity I. On taking logarithm of two intensities of solar power, I_1 and I_2, provides intensity difference. It is mathematically expressed as:

$$Sol = \log\left(I_1\right)\left(I_2\right)^{-1} \tag{2}$$

where logarithmic unit ratio for noise of sol is expressed as *Sol*. The oncisol (oS) is more convenient for solar power systems. The mathematical expression by the following equality gives an oncisol (oS), which is 1/11th unit of a *Sol*:

$$oS = \pm 11 \log\left(I_1\right)\left(I_2\right)^{-1} \tag{3}$$

Noise of therm: for a pack of heat energy wave, the multiplication of total power storage and the velocity of light gives heat power intensity I. The pack of solar energy wave and heat energy wave (for same intensity I), have same energy areas, therefore their units of noise are same as *Sol*.

Noise of photons: for a pack of light energy beam, the multiplication of total power storage and the velocity of light gives light power intensity I. The pack of solar energy wave and light energy beam (for same intensity I), have same energy areas, therefore their units of noise are same as *Sol*.

Noise of electrons: for a pack of electricity wave, the multiplication of total electrical storage and the velocity of light gives electrical power intensity I. The pack of solar energy wave and electricity wave (for same intensity I), have same energy areas, therefore their units of noise are same as *Sol*.

Noise of scattering: for a pack of fluid energy wave, the multiplication of total power storage and the velocity of fluid gives fluid power intensity I. On taking logarithm of two intensities of fluid power, I_1 and I_2, provides intensity difference. It is mathematically expressed as:

$$Sip = \log(I_1)(I_2)^{-1} \tag{4}$$

where logarithmic unit ratio for noise of scattering is *Sip*. The oncisip (oS) is more convenient for fluid power systems.

The mathematical expression by the following equality gives an oncisip (oS), which is 1/11th unit of a *Sip*:

$$oS = \pm 11 \log(I_1)(I_2)^{-1} \tag{5}$$

For energy area determination for a fluid wave, the water with a specific gravity of 1.0 is the standard fluid considered with power of ±1 Wm^{-2} for a reference intensity I_2.

Noise of scattering and lightning: for a pack of fire wave, the intensity, I, of fire flash with power of light, is the multiplication of total power storage and the velocity of light. Whereas for a pack of fire wave, the intensity, I, of fire flash with power of fluid, is the multiplication of total power storage capacity and velocity of fluid.

- For a noise due to fire flash, the collective effect of scattering and lightning is obtained by superimposition principle.

- For same intensity I, the pack of solar energy wave and a fire flash with light power have same energy areas; therefore, their units of noise are same as *Sol*. The therm power may also be included in fire flash with power of light.

- For same intensity I, the pack of fluid energy wave and a fire flash with fluid power have same energy areas; therefore, their units of noise are same as *Sip*. In determining the areas of energy for the case of fluids other than water, a multiplication factor in specific gravity has to be evaluated.

Noise of elasticity: for a pack of sound energy wave, the product of total power storage and the velocity of sound gives sound power intensity I. On taking logarithm of two intensities of sound power, I_1 and I_2, provides intensity difference. It is mathematically expressed as:

$$Bel = \log(I_1)(I_2)^{-1} \tag{6}$$

where logarithmic unit ratio for noise of elasticity is *Bel*. The oncibel (oB) is more convenient for sound power systems. The mathematical expression by the following equality gives an oncibel (oB), which is 1/11th unit of a *Bel*:

$$oB = \pm 11 \log(I_1)(I_2)^{-1} \tag{7}$$

There are following elaborative points on choosing an *onci* as 1/11th unit of noise [37]:

Reference value used for I_2 is –1 W m^{-2} on positive scale of noise and 1 W m^{-2} on negative scale of noise. In a power cycle, all types of wave form one positive power cycle and one negative power cycle [15]. Positive scale of noise has 10 positive units and 1 negative unit, whereas negative scale of noise has 1 positive unit and 10 negative units:

i. Each unit of sol, sip and bel is divided into 11 parts, 1 part is 1/11th unit of noise;

ii. The base of logarithm used in noise measurement equations is 11.

Reference value of I_2 is –1 W m^{-2} with I_1 on positive scale of noise, should be taken with negative noise measurement expression (see Eqs. 3, 5 and 7), therefore it gives positive values of noise;

Reference value of I_2 is 1 W m^{-2} with I_1 on negative scale of noise, should be taken with positive noise measurement expression (see Eqs. 3, 5 and 7), therefore it gives negative values of noise.

The choosing of *onci* in noise units is done so as to have separate market product and system of noise scales and their units distinguished from prevailing *decibel* units (which have its limitations) in the International System of Units. More discussions on energy conversion, noise characterization theory and choice of noise scales and its units are presented in many papers by the author [1–60].

3.2 Noise reduction coefficients

Noise reduction coefficient for noise of sol (thermal power):

$$NRC = 1 - 11^{-\Delta oS/22} \tag{8}$$

where ΔoS is noise of therm reduction (noise transmission loss) in oncisol.

Noise reduction coefficient for noise of sip (fluid power):

$$NRC = 1 - 11^{-\Delta oSi/22} \tag{9}$$

where ΔoSi is noise of scattering reduction (noise transmission loss) in oncisip.

Noise reduction coefficient for noise of bel (sound power)

$$NRC = 1 - 11^{-\Delta oB/22} \tag{10}$$

where ΔoB is noise of elasticity reduction (noise transmission loss) in oncibel.

4. Model assumptions and development

The picture of the experimental setup in a prefabricated outdoor room is presented in **Figure 3**. The solar noon annual solstices and equinoxes days are selected for performing sensitivity analysis to achieve range of: (i) temperatures of pre-conditioned fresh air available; (ii) electric power generation vis-à-vis surface temperatures of photovoltaic modules; (iii) integrated noise insulation values due to noise fields of composite wave elements transmitted into the room. Computer aided simulation model is developed for an airflow window system located in Montréal. Some examples of noise insulation calculations are illustrated using newly devised noise measurement equations for noise of sol, noise of therm, noise of scattering

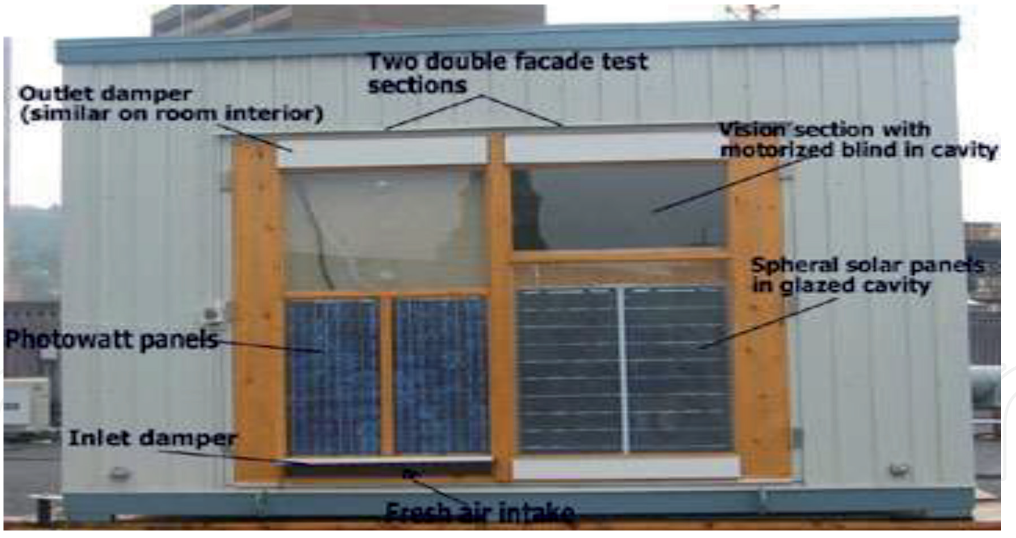

Figure 3.
Prefabricated outdoor room at Concordia University.

and noise of elasticity. The sensitivity analysis for an outdoor duct is also conducted for critical design of ventilation requirements with supply of varying outdoor mass flow rate to a single building zone. The improved method is useful for accurately predicting ventilation air requirements along with designing integrated thermal and sound insulation through a double or cavity wall building structure.

Table 3 has provided properties of physical domain. **Tables 4**–**10** have presented sensitivity analysis and noise characterization values for the exterior duct based on mass flow rate, solar irradiation and size of duct. The thermal modeling results are presented in **Figures 4**–**8**. **Figure 4** has presented efficiencies of the building integrated photovoltaic airflow window system viz., electrical efficiency of PV module and combined efficiency of the system. **Figure 5** has presented thermal model results of PV Module, insulation panel and air with respect to height of the spandrel section. **Figure 6** has presented thermal model results for PV module temperatures with solar time for forced and natural convection and air temperatures for forced and natural convection for air cavities I and II. **Figure 7** has results for useful energy generated and solar energy absorbed by a photovoltaic module. **Figure 8** has provided variation of hydraulic diameter, velocity and flow rate vs. pressure drop on a log scale.

The thermo-physical properties of photovoltaic modules, air and insulating panel were assumed constant along all directions i.e. x-, y-, and z-ordinates. The thermo-physical properties of insulating panel with building insulation were obtained from tests conducted with heat flow meter and related specifications from the manufacturer [3]. The temperature differences along x-direction are obtained by assuming same temperature difference per unit thickness of material along x- and y-ordinates [3]. The heat storage capacity for temperature differences across x-direction is negligible of the heat storage capacity for temperature differences across y-direction. Therefore temperatures are assumed uniform and lumped in x-direction. The pair of glass coated photovoltaic modules was having three layers of material viz., a flat sheet of solar cells, with glass face sheets on its exterior and interior sides. The measurements were collected for a pair of successive runs at same solar intensities [3]. The thermal model is validated by comparing its predicted results with those obtained from the experimental apparatus. The agreement between the predictions of the thermal model and experimental results was presented to be very good [3].

Property	Value	Property	Value
Solar irradiation	650 W m^{-2}	Width of air gap	0.025 m
Ambient heat transfer coefficient	13.5 W m^{-2} K^{-1}	Thermal conductivity of air	0.02624 W m^{-1} K^{-1}
Ambient air temperature	−5°C	Specific heat of air (Cp)	1000 J kg^{-1} K^{-1}
Building space temperature	20°C	Density of air	1.1174 kg m^{-3}
Height of duct	3.0 m	Kinematic viscosity of air	15.69×10^{-6} m^2 s^{-1}
Width of duct	1.0 m	Prandtl number of air	0.708
Thickness of outer wall of duct	0.0025 m	Air velocity for obtaining mass flow rate	0.75 m s^{-1}
Absorptance of outer wall with flat black paint	0.95	Stefan Boltzmann constant for surface of duct walls	5.67×10^{-8} W m^{-2} K^{-4}
Thermal conductivity of aluminum alloy for HVAC duct	137 W m^{-1} K^{-1}	Emissivity of back surface of duct walls	0.95
RSI value	1.0 m^2 K W^{-1}	Number of nodes in x direction	Nx = 3
Thickness	0.04 m	Number of nodes in y direction	Ny = 10, Δy = 0.3 m

Table 3.
Properties of physical domain.

Solar irradiation (Wm^{-2})	Air temperature difference (ΔT) °C	Noise of sol oS (oncisol)
450	15.50	28
550	18.90	28.93
650	22.40	29.7
750	25.90	30.36
850	29.40	30.91

Table 4.
Temperature difference and noise of sol with solar irradiation (air velocity: 0.75 ms^{-1}).

Air velocity (ms^{-1})	Fluid power (Wm^{-2})	Air temperature difference (ΔT) °C	Noise of scattering oS (oncisip)
1.35	47.62	15.28	17.72
1.05	37.0	18.22	16.50
0.75	26.45	22.40	15.02
0.45	15.87	28.15	12.65
0.15	05.29	29.80	07.64

Table 5.
Temperature difference and noise of scattering with air velocity (S = 650 Wm^{-2}).

(ΔT) °C	Mass flow rate ($kg\ s^{-1}$)	Thermal power (Wm^{-2})	Noise of therm oS (oncisol)	(ΔT) °C	Mass flow rate ($kg\ s^{-1}$)	Thermal power (Wm^{-2})	Noise of therm oS (oncisol)
15.50	0.01376	71.09	19.5602	15.28	0.0231	117.65	21.868
18.90	0.01275	80.325	20.119	18.22	0.0171	103.85	21.296
22.40	0.0120	89.6	20.614	22.40	0.0120	89.6	20.614
25.90	0.0115	99.2833	21.043	28.15	8.1×10^{-3}	76.0	19.866
29.40	0.0111	108.78	21.505	29.80	6.2×10^{-3}	61.59	18.898

Table 6.
Mass flow rate and noise of therm with (ΔT) °C.

Air velocity ($m{\cdot}s^{-1}$)	Fluid power ($W{\cdot}m^{-2}$)	Noise of scattering oS (oncisip)	Sound pressure ($N{\cdot}m^{-2}$)	Sound power intensity ($W{\cdot}m^{-2}$)	Noise of elasticity oB (oncibel)
1.35	47.62	17.72	557.5	752.7	30.36
1.05	37.0	16.50	433.65	455.33	28.05
0.75	26.45	15.02	309.75	232.31	24.97
0.45	15.87	12.65	185.85	83.63	20.24
0.15	05.29	07.64	61.94	09.29	10.12

Table 7.
Noise of elasticity with air particle velocity (impedance $Z_0 = 413\ N{\cdot}s{\cdot}m^{-3}$ at 20°C).

Noise of therm oS (oncisol)—duct	(ΔT) °C—room	Mass flow rate ($kg\ s^{-1}$)—room	Noise of therm oS (oncisol)—room	Transmission loss ΔoS (oncisol)	Noise reduction coefficient
21.868	25	0.02095	28.721	6.853	0.52619

Table 8.
Thermo-fluid noise transmission loss and noise reduction coefficient.

Noise of elasticity oB (oncibel)—duct $v = 0.75\ m{\cdot}s^{-1}$	Noise of elasticity oB (oncibel)—room $v = 0.15\ m{\cdot}s^{-1}$	Transmission loss ΔoB (oncibel)	Noise reduction coefficient
24.97	9.29	15.68	0.81896

Table 9.
Acoustic noise transmission loss and noise reduction coefficient.

Noise of scattering oS (oncisip)—duct $v = 0.75\ m{\cdot}s^{-1}$	Noise of scattering oS (oncisip)—room $v = 0.15\ m{\cdot}s^{-1}$	Transmission loss ΔoS (oncisip)	Noise reduction coefficient
15.02	7.64	7.38	0.55264

Table 10.
Fluid noise transmission loss and noise reduction coefficient.

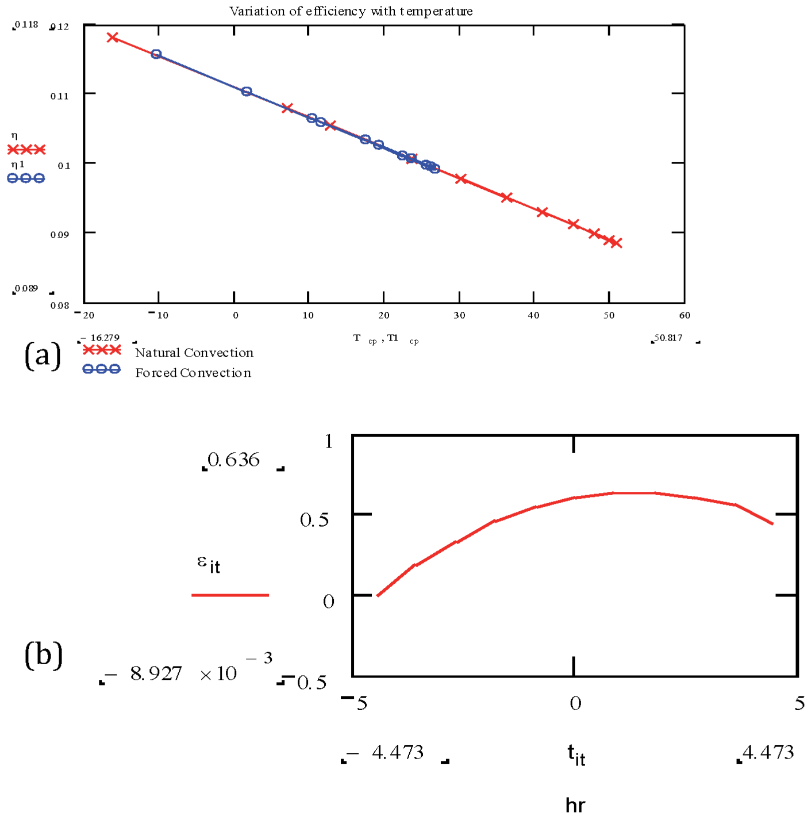

Figure 4.
Efficiencies: (a) electrical efficiency of PV module and (b) combined efficiency of the system.

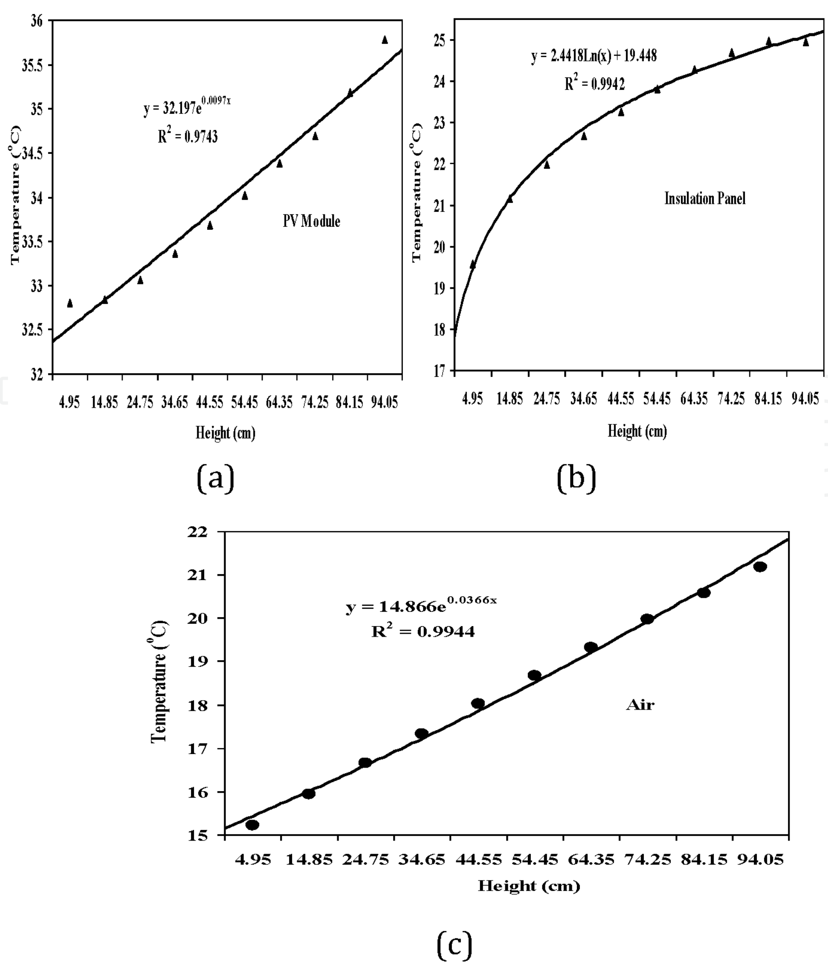

Figure 5.
Thermal model results: (a) PV module, (b) insulation panel, and (c) air.

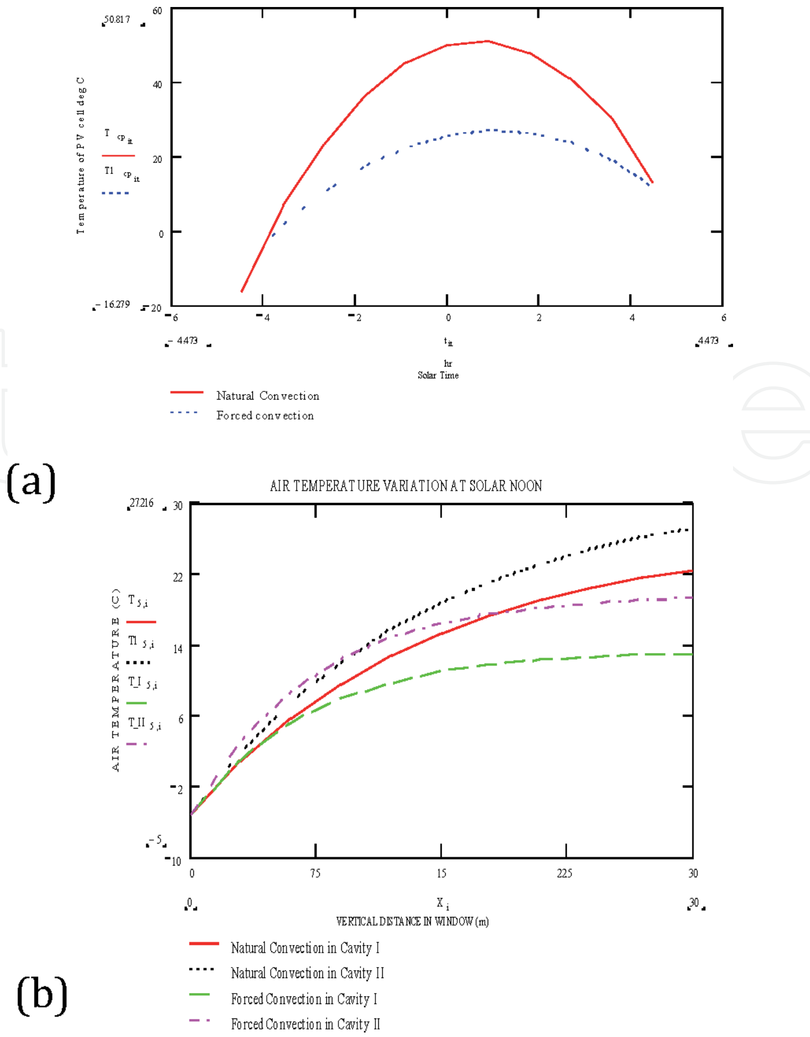

Figure 6.
Thermal model results: (a) PV module temperatures and (b) air temperatures.

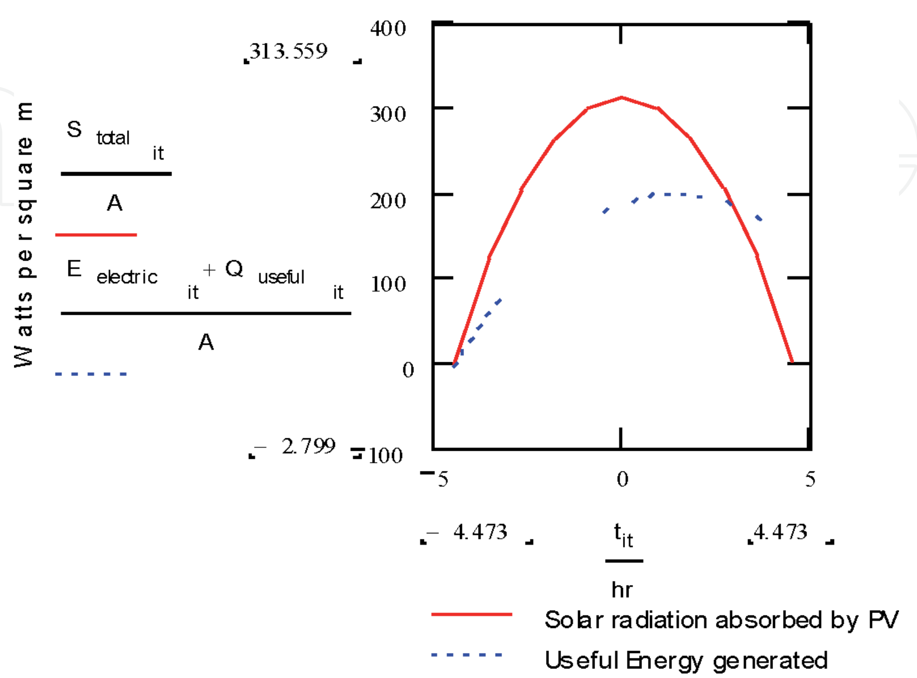

Figure 7.
Useful energy generated and solar energy absorbed by a photovoltaic module.

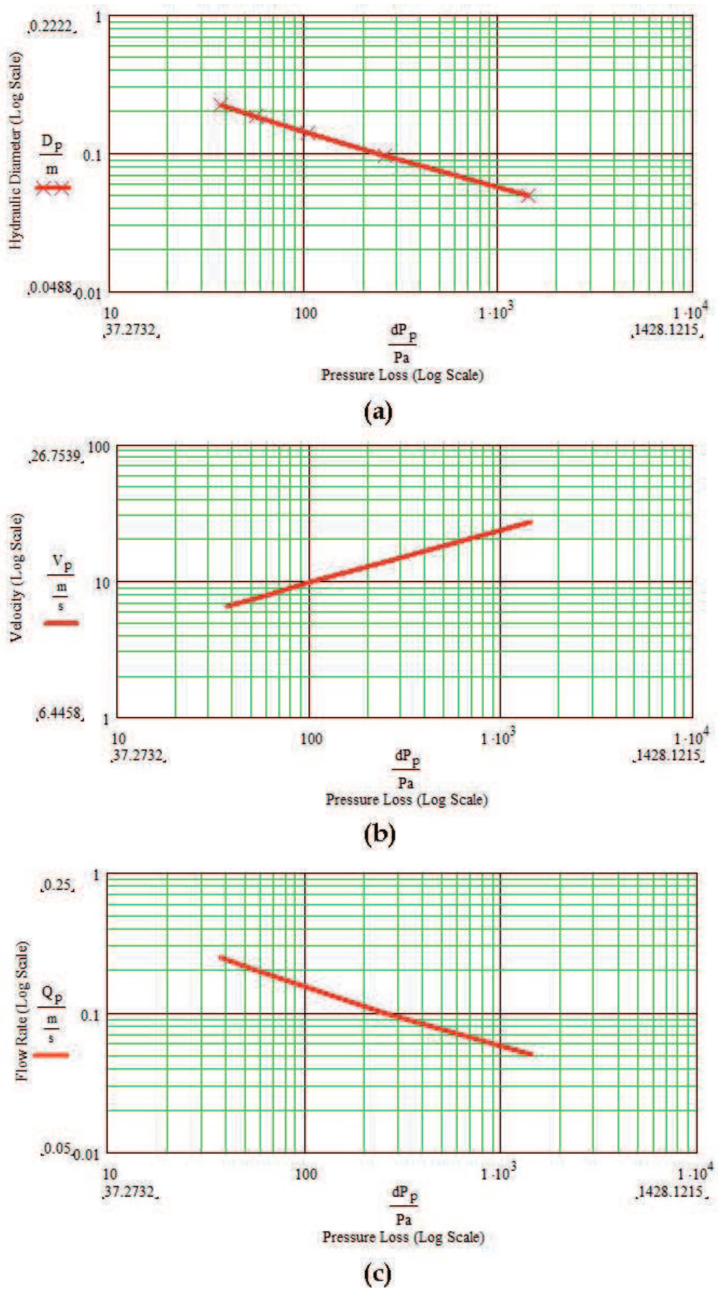

Figure 8.
Variation of (a) hydraulic diameter, (b) velocity, and (c) flow rate vs. pressure drop on a log scale.

5. Conclusion

A study on integrated insulation modeling of an airflow window with a PV solar wall via energy conversion is performed. The noise interference and characterization equations as per speed of a composite wave are presented. The sources of noise measurement equations (sun, light, sound, heat, electricity, fluid and fire) are described depending on their speed of noise interference. Noise measurement equations and their units are coined. The acoustic insulation systems are classified as per source signals of solar power, electric power, light power, sound power, heat power, fluid power and fire power. Based on sensitivity analysis conducted on an outdoor duct exposed to solar radiation, integrated insulation model has calculated noise transmission losses and noise reduction coefficients, besides calculating individual values of oncisol, oncisip and oncibel for various types of noises.

Several performance and optimization issues are considered in development of the model including optimal air velocity for heat transfer, dimensions of PV module (height), selection of cavity width to reduce pressure drops, and prediction of temperature rise of air as it flows out of the airflow window system and into the outdoor test-room. The airflow is adjusted to a constant value to optimize necessary temperature for integrated photovoltaic array as well as for pre-heated fresh air into the outdoor test-room. It is envisaged that inside an airflow window integrated with PV, cooling by forced convection is essential, without which, the temperature of PV cell reaches very high (51°C), which decreases the efficiency by more than 20% [4]. The combined efficiency (electrical and thermal) of the system reaches 50%.

A building integrated photovoltaic airflow window (BIPV-AW) system is developed for the purpose of combined generation of electricity, thermal energy and daylighting. This approach will have additional following advantages: (a) there will be reduction in peak heating loads, which will reduce the required capacity of the heating/cooling system; (b) there will be reduction in energy consumed for heating and lighting in the building; and (c) electricity demand of the building will be reduced and energy utilities will get peak surplus.

Acknowledgements

The author conducted part of the work at Department of Building, Civil and Environmental Engineering, Concordia University, Montréal, Québec, Canada.

Author details

Himanshu Dehra
Monarchy of Concordia, India

*Address all correspondence to: anshu_dehra@hotmail.com

References

[1] Asdrubali F, D'Alessandro F, Schiavoni S. A review of unconventional sustainable building insulation materials. Sustainable Materials and Technologies. 2015;**4**:1-17

[2] Asdrubali F, Schiavoni S, Horoshenkov KV. Review of sustainable materials for acoustic applications. Building Acoustics. 2012;**19**(4):283-312

[3] Dehra H. A numerical and experimental study for generation of electric and thermal power with photovoltaic modules embedded in building façade [submitted/unpublished PhD dissertation]. Montréal, Québec, Canada: Department of Building, Civil and Environmental Engineering, Concordia University; 30 August 2004. p. 120

[4] Dehra H. Modelling of airflow window with integrated photovoltaics [doctoral seminar]. Montréal, Canada: Department of Building, Civil and Environmental Engineering, Concordia University; 2002

[5] Dehra H. A 1-D/2-D model for an exterior HVAC rectangular duct with a steady solar heat flux generation. In: Orally Presented at the Proceedings of the Second International Green Energy Conference; 25-29 June 2006; Oshawa, Canada. 2006. pp. 1240-1251

[6] Dehra H. The effect of heat and thermal storage capacities of photovoltaic duct wall on co-generation of electric and thermal power. In: Orally Presented in the Proceedings of American Institute of Chemical Engineers - AIChE 2007 Spring Meeting; 22-26 April 2007; Houston, Texas, USA; Session 36a. 2007 (9 pages). Available from: https://www3.aiche.org/proceedings/Abstract.aspx?PaperID=79681

[7] Dehra H. On solar building energy devices. In: Orally Presented at the 18th IASTED International Conference on Modelling and Simulation; 30 May-1 June 2007; Montréal, Canada. 2007. pp. 96-101. Available from: https://www.iasted.org/conferences/servepdf-567.html?name=FinalProgram.pdf; http://dl.acm.org/citation.cfm?id=1295663

[8] Dehra H. A heat transmission model for a telephone line. In: Orally Presented at the 21st Canadian Congress of Applied Mechanics, Department of Mechanical & Industrial Engineering, Ryerson University; 3-7 June 2007; Toronto, Ontario, Canada. 2007. pp. 356-357. Available from: http://www.worldcat.org/title/cancam-2007-21st-canadian-congress-of-applied-mechanics-ryerson-university-toronto-ontario-canada-june-3-7-2007-proceedings-le-21ieme-congres-canadien-de-mecanique-appliquee-comptes-rendus/oclc/500984841

[9] Dehra H. The study of a solar cell device under illumination. In: Orally Presented at the 21st Canadian Congress of Applied Mechanics, Department of Mechanical & Industrial Engineering, Ryerson University; 3-7 June 2007; Toronto, Ontario, Canada. 2007. pp. 354-355. Available from: http://www.worldcat.org/title/cancam-2007-21st-canadian-congress-of-applied-mechanics-ryerson-university-toronto-ontario-canada-june-3-7-2007-proceedings-le-21ieme-congres-canadien-de-mecanique-appliquee-comptes-rendus/oclc/500984841

[10] Dehra H. Thermal modelling of an airflow window with a photovoltaic solar wall. In: Accepted Abstract in the Proceedings of The 3rd International Energy, Exergy and Environment Symposium; 1-5 July 2007; Évora, Portugal. 2007 (1 page)

[11] Dehra H. The electrodynamics of a pair of PV modules with connected building resistance. In: Presented at The 3rd IASME/WSEAS International Conference on Energy, Environment, Ecosystems and Sustainable Development (EEESD'07); 24-26 July 2007; Agios Nikolaos, Crete Island, Greece. 2007. pp. 563-567. Available from: http://www.wseas.us/e-library/conferences/2007creteeeesd/papers/562-125.pdf

[12] Dehra H. A unified theory for stresses and oscillations. In: Orally Presented at the Canadian Acoustical Association (CAA) Montréal 2007 Conference, Concordia University; 9-12 October 2007; Montréal, Canada. 2007. pp. 132-133. Available from: https://jcaa.caa-aca.ca/index.php/jcaa/article/view/1936

[13] Dehra H. A model for stresses and oscillations of a resonant cavity wall. In: Accepted Abstract for an Oral Presentation at 57th Canadian Chemical Engineering Conference; 28-31 October 2007; Edmonton, Alberta, Canada. 2007 (1 page). Available from: http://csche2007.cheminst.ca/00000039.htm

[14] Dehra H. Mathematical analysis of a solar thermosyphon. In: Accepted for an Oral Presentation at the 1st International Conference on Advances in Energy Research, Indian Institute of Technology (IIT) Bombay; 12-14 December 2007, Mumbai, India. 2007 (6 pages). Available from: http://www.printsasia.com/book/international-conference-on-advances-in-energy-research-icaer-2007-proceedings-of-the-first-international-023063432x-9780230634329

[15] Dehra H. Power transfer and inductance in a star connected 3-phase RC circuit amplifier. In: Proceedings of American Institute of Chemical Engineers - AIChE 2008 Spring Meeting; 6-10 April 2008; New Orleans, LA, USA; Session 96a. 2008 (7 pages). Available from: https://aiche.confex.com/aiche/s08/techprogram/P103422.HTM

[16] Dehra H. The representation of units on hexagonal scales of noise. In: Accepted Abstract in the Proceedings of the 58th Canadian Chemical Engineering Conference; 19-22 October 2008; Ottawa, Ontario, Canada. 2008 (1 page). Available from: http://csche2008.cheminst.ca/00001032.htm

[17] Dehra H. A benchmark solution for interference of noise waves. In: AIChE Spring 2009; 26-30 April 2009; Tampa, FL, USA; Session 67c. 2009 (4 pages). Available from: https://aiche.confex.com/aiche/s09/webprogram/Paper143116.html

[18] Dehra H. A guide for signal processing of sensors and transducers. In: AIChE Spring 2009; 26-30 April 2009; Tampa, FL, USA; Session 6b. 2009 (9 pages). Available from: https://aiche.confex.com/aiche/s09/webprogram/Paper143251.html

[19] Dehra H. Acoustic filters. In: Proceedings National Conference on Renewable Energy (NaCORE 2009); 5-7 November 2009; Jodhpur, Rajasthan, India. 2009. pp. 164-168. Available from: http://www.dkagencies.com/doc/from/1123/to/1123/bkId/DK913321716276739525111756l/details.html

[20] Dehra H. Ventilation materials characterisation of a solar panel duct wall. In: Proceedings National Conference on Renewable Energy (NaCORE 2009); 5-7 November 2009; Jodhpur, Rajasthan, India. 2009. pp. 235-241. Available from: http://www.dkagencies.com/doc/from/1123/to/1123/bkId/DK913321716276739525111756l/details.html

[21] Dehra H. A building integrated photovoltaic airflow window system. In: 2nd International Conference on Advances in Energy Research, Indian

Institute of Technology (IIT) Bombay, Mumbai, India, December 09-11, 2009 (6 pages)

[22] Dehra H. Experiments on photovoltaic modules embedded in building façade. In: AIChE Spring 2010; 21-25 March 2010; San Antonio, TX, USA; Session 38b. 2010 (9 pages). Available from: https://www3.aiche.org/proceedings/Abstract.aspx?PaperID=171997

[23] Dehra H. A monitoring model for a fan operated photovoltaic hybrid air ventilation system. In: AIChE Spring 2010; 21-25 March 2010; San Antonio, TX, USA; Session 143b. 2010 (11 pages). Available from: https://www.aiche.org/conferences/aiche-spring-meeting-and-global-congress-on-process-safety/2010/proceeding/paper/143b-monitoring-model-fan-operated-photovoltaic-hybrid-air-ventilation-system-0

[24] Dehra H. A design tool for an outdoor duct. In: Proceedings 9th International Conference on Sustainable Energy Technologies (SET 2010), Shanghai Jiao Tong University School of Medicine; 24-27 August 2010; Shanghai, China. 2010 (7 pages). Available from: http://www.worldcat.org/title/9th-international-conference-on-sustainable-energy-technologies-set-2010/oclc/729681678

[25] Dehra H. A portable solar farm house. In: AIChE Spring 2011; 13-17 March, 2011; Chicago, IL, USA; Session 116d. 2011 (9 pages). Available from: https://www3.aiche.org/proceedings/Abstract.aspx?PaperID=210477

[26] Dehra H. A slide rule for noise measurement. In: 10th International Conference on Sustainable Energy Technologies (SET 2011); 4-7 September 2011; Istanbul, Turkey. 2011 (5 pages). Available from: https://www.scribd.com/document/106892829/Programme-Final

[27] Dehra H. Modelling of an airflow window with a photovoltaic solar wall. In: 10th International Conference on Sustainable Energy Technologies (SET 2011); 4-7 September 2011; Istanbul, Turkey. 2011 (6 pages). Available from: https://www.scribd.com/document/106892829/Programme-Final

[28] Dehra H. Numerical simulations and experiments on a photovoltaic solar wall. In: Accepted Abstract in AIChE Spring 2012; 1-5 April 2012; Houston, TX, USA; Session 91b. 2012 (1 page). Available from: https://www.aiche.org/conferences/aiche-spring-meeting-and-global-congress-on-process-safety/2012/proceeding/paper/91b-numerical-simulations-and-experiments-on-photovoltaic-solar-wall-0

[29] Dehra H. Photovoltaic solar wall: 2-D numerical modeling and experimental testing under fan induced hybrid ventilation. In: Orally Presented at the IEEE International Conference on Energy Efficient Technologies for Sustainability; St. Xavier's Catholic College of Engineering, Nagercoil, Kanyakumari District, Tamil Nadu, India, IEEE Xplore; 7-8 April 2016. pp. 668-676. Available from: http://ieeexplore.ieee.org/document/7583836/

[30] Dehra H. A novel theory of psychoacoustics on noise sources, noise measurements and noise filters. In: Orally Presented at the NoiseCon16; 13-15 June 2016; Providence, Rhode Island. USA: Institute of Noise Control Engineering; 2016. pp. 933-942. Available from: http://www.ingentaconnect.com/contentone/ince/incecp/2016/00000252/00000001/art00008?crawler=true

[31] Dehra H. On sources and measurement units of noise.

In: Orally Presented at the International Conference on Innovation, Management and Industrial Engineering (IMIE 2016); 5-7 August 2016; Kurume, Fukuoka, Japan. 2016. pp. 219-227. Available from: http://iainst.org/imie2016/

[32] Dehra H. A paradigm for characterization and checking of a human noise behavior. In: WASET Proceedings of 19th International Conference on Psychological and Brain Sciences; 11-12 May 2017; Montréal, Canada. 2017. pp. 658-666. Available from: https://www.waset.org/downloads/17/presentations/17ca050361.pdf; https://www.waset.org/abstracts/70655

[33] Dehra H. Electrical and thermal characteristics of a photovoltaic solar wall with passive and active ventilation through a room. In: WASET Proceedings of 19th International Conference on Sustainable and Renewable Energy Engineering; 11-12 May 2017; Montréal, Canada. 2017. pp. 584-592. Available from: https://www.waset.org/downloads/17/presentations/17ca050297.pdf

[34] Dehra H. A multi-parametric PV solar wall device. In: Proceedings of IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI-2017); 21-22 September 2017; Chennai, India. IEEE; 2017. pp. 392-401. Available from: https://ieeexplore.ieee.org/document/8392324/

[35] Dehra H. Characterization of noise in power systems. In: Orally Presented at IEEE International Conference on Power Energy, Environment & Intelligent Control (PEEIC2018); 13-14 April 2018; Greater Noida, India. IEEE; 2018. pp. 321-330. Available from: http://www.glbitm.org/PEEIC/index.html

[36] Dehra H. A paradigm of noise interference in a wave. In: Internoise-2018, Orally Presented at 47th International Congress and Exposition on Noise Control Engineering; 26-29 August 2018; Chicago, Illinois, USA. 2018. pp. 451-462. Available from: https://internoise2018.org/

[37] Dehra H. Acoustic signal processing and noise characterization theory via energy conversion in a PV solar wall device with ventilation through a room. Advances in Science, Technology and Engineering Systems Journal. 2018;**3**(4):130-172

[38] Dehra H. The entropy matrix generated exergy model for a photovoltaic heat exchanger under critical operating conditions. International Journal of Exergy. 2008;**5**(2):132-149. DOI: 10.1504/IJEX.2008.016671. Available from: http://www.inderscience.com/info/inarticle.php?artid=16671

[39] Dehra H. The noise scales and their units. Canadian Acoustics. 2008;**36**(3):78-79

[40] Dehra H. A two dimensional thermal network model for a photovoltaic solar wall. Solar Energy. 2009;**83**(11):1933-1942. DOI: 10.1016/j.solener.2008.07.014. Available from: http://www.sciencedirect.com/science/article/pii/S0038092X08001862

[41] Dehra H. A combined solar photovoltaic distributed energy source appliance. Natural Resources. 2011;**2**(2):75-86. DOI: 10.4236/nr.2011.22010. Available from: http://www.scirp.org/journal/PaperInformation.aspx?PaperID=5258

[42] Dehra H. A theory of acoustics in solar energy. Natural Resources. 2013;**4**(1A):116-120. DOI: 10.4236/nr.2013.41A014. Available from: http://www.scirp.org/journal/PaperInformation.aspx?PaperID=29361

[43] Dehra H. A mathematical model of a solar air thermosyphon integrated with building envelope. International Journal of Thermal Sciences. 2016;**102**:210-227. DOI: 10.1016/j.ijthermalsci.2015.11.022. Available from: http://www.sciencedirect.com/science/article/pii/S1290072915003750

[44] Dehra H. Photovoltaic solar wall: 2-D numerical modeling and experimental testing under fan induced hybrid ventilation. New York, USA: IEEE Xplore. 2016. pp. 668-676. Available from: http://ieeexplore.ieee.org/document/7583836/

[45] Dehra H. An investigation on energy performance assessment of a photovoltaic solar wall under buoyancy-induced and fan-assisted ventilation system. Amsterdam, Netherlands: Applied Energy. 2017;**191**:55-74. DOI: 10.1016/j.apenergy.2017.01.038. Available from: http://www.sciencedirect.com/science/article/pii/S0306261917300466

[46] Dehra H. Acoustic signal processing and noise characterization theory via energy conversion in a PV solar wall device with ventilation through a room. Advances in Science, Technology and Engineering Systems Journal. 2018;**3**(4):130-172. DOI: 10.25046/aj030414. Available from: https://www.astesj.com/publications/ASTESJ_030414.pdf; https://astesj.com/v03/i04/p14/

[47] Dehra H. Acoustic filters for sensors and transducers, ICAE2018. Energy Procedia. 2019;**158**:4023-4030. DOI: 10.1016/j.egypro.2019.01.837

[48] Dehra H. Modeling of energy conversion and noise characterization in outdoor ducts exposed to solar radiation, ICAE2018. Energy Procedia. 2019;**158**:5162-5168. DOI: 10.1016/j.egypro.2019.01.681. Available from: https://www.sciencedirect.com/science/article/pii/S1876610219307167/pdfft?md5=25603d1f35661f3b43beb6e295763507&pid=1-s2.0-S1876610219307167-main.pdf

[49] Dehra H. Principles of energy conversion and noise characterization in air ventilation ducts exposed to solar radiation, special section: ICAE2018. Applied Energy. 2019;**242C**:1320-1345. DOI: 10.1016/j.apenergy.2019.03.013. Available from: https://www.sciencedirect.com/science/article/pii/S0306261919304040

[50] Dehra H. Characterization of noise in power systems. New York, USA: IEEE Xplore. IEEE; 2019. pp. 320-329. DOI: 10.1109/PEEIC.2018.8665443. Available from: https://ieeexplore.ieee.org/document/8665443

[51] Dehra H. Monarchy of Concordia: A globalized society on maintaining peace and harmony in the world by controlling human noise behavior. International Journal of Social Sciences. 2020;**9**(1). DOI: 10.20472/SS2020.9.1.001. Available from: www.iises.net; https://www.iises.net/international-journal-of-social-sciences/publication-detail-25601; https://www.iises.net/international-journal-of-social-sciences/publication-detail-25601?download=1

[52] Dehra H. Data for Monarchy of Concordia: A Globalized Society on Maintaining Peace and Harmony in the World by Controlling Human Noise Behavior (Version v1) [Data Set]. Geneva, Switzerland: Zenodo; 2019. DOI: 10.5281/zenodo.3515734

[53] Dehra H. Solar energy absorbers. In: Manyala R, editor. Solar Collectors and Panels, Theory and Applications. London, UK: InTechOpen; 2010. pp. 111-134. DOI: 10.5772/10334. Available from: https://www.intechopen.com/books/solar-collectors-and-panels--theory-and-applications/solar-energy-absorbers

[54] Dehra H. Acoustic filters. In: Romano VA, Duval AS, editors.

Ventilation: Types, Standards and Problems. New York, USA: Nova Publishers; 2012. pp. 135-154. Available from: https://www.novapublishers.com/catalog/product_info.php?products_id=40124&osCsid=a5b966ac2674b1639843fc0b6d201172

[55] Dehra H. Solar thermosyphon. In: Méndez-Vilas A, editor. Materials and Processes for Energy: Communicating Current Research and Technological Developments, Formatex Energy Book Series. 2013. pp. 142-149

[56] Dehra H. Chapter 11: A theory of acoustics in solar energy. In: Keach S, editor. Recent Progress in Natural Resources. New York, USA. Vol. 2. Academic Pages; 2017. pp. 77-81

[57] Dehra H. Chapter 15: Building-integrated thermoelectric cooling-photovoltaic (TEC-PV) devices. In: Aranguren P, editor. Bringing Thermoelectricity into Reality. London, UK: IntechOpen; 2018. pp. 313-330. DOI: 10.5772/intechopen.75472. Available from: https://www.intechopen.com/books/bringing-thermoelectricity-into-reality/building-integrated-thermoelectric-cooling-photovoltaic-tec-pv-devices

[58] Dehra H. Chapter 1: Solar energy conversion and noise characterization in photovoltaic devices with ventilation. In: Prabaharan N, Rosen MA, Campana PE, editors. Recent Developments in Photovoltaic Materials and Devices. London, UK: IntechOpen; 2019. pp. 1-20. DOI: 10.5772/intechopen.79706. Available from: https://www.intechopen.com/chapter/pdf-download/62929

[59] Dehra H. Acoustic filters for sensors and transducers: Energy policy instrument for monitoring and evaluating holy places and their habitants. In: Taner T, editor. Energy Policy. London, UK: IntechOpen; 2019. DOI: 10.5772/intechopen.81949. Available from: https://www.intechopen.com/chapter/pdf-download/64590

[60] Dehra H. Noise calculation charts and indoor environmental quality for evaluating industrial indoor environment and health. In: Korhan O, editor. Indoor Environment and Health. London, UK: IntechOpen; 2019. DOI: 10.5772/intechopen.84993. Available from: https://www.intechopen.com/chapter/pdf-download/67373