Assessment of desiccant assisted compression and absorption based air-conditioning systems for hot-dry and composite climates

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Abstract. Air-conditioning inside residential and commercial buildings shows considerable amount of energy consumption among other energy consuming components. The present study is aimed at discussing the performance of desiccant integrated air-conditioning systems using solar energy and biomass resources through EnergyPlus simulations. Validations of the selected building and system are done with codes and standards available in the literature. Conventionally available high grade electricity is used as an auxiliary source. In this work, the study is carried out for hot-dry and composite climates using desiccant and indirect evaporative cooling assisted compression and absorption based air-conditioning systems. Performance parameters in terms of heat energy, electricity consumption and the coefficient of performance are studied. From the simulation results, it is envisaged that absorption-based air-conditioning system possesses more electricity saving potential than compression-based system for achieving the same thermal comfort condition. It is found that, as compared to compression-based system, 46.57% and 46.14% electricity savings can be acquired using absorption-based technology for hot-dry and composite climates, respectively.

1. Introduction
Continuously increasing population, air pollution and living standards have increased the air-conditioning demand in the residential as well as commercial building sectors [1]. This increased energy demand is also indirectly affecting our natural resources and causing several harmful effects on human health and the environment. Various air-conditioning technologies are available in the market and most of them are operated through vapor-compression (VC) based systems. High energy consumption is main concern in these VC-based systems. Till now, various advancements have been done in order to improve the energy performance of these systems in terms of the coefficient of performance (COP) and energy consumption. For example, Sung et al. [2] introduced a new kind of VC system incorporating different vane compressor in place of conventional compressor. They reported the averaged COP of 2.15 of the new system. Harby et al. [3] studied the performance of a VC system using evaporative condensing unit and revealed considerable amount of energy reduction. Further, Rostamzadeh et al. [4] introduced a novel dual loop bi-evaporator VC-based system. They carried out economic, exergy and exergo-economic analysis of the proposed system and suggested various modifications to improve the COP under different operating conditions.
Decoupling strategy in the field of air-conditioning is an emerging technology to ensure better energy performance from air-conditioners [5]. Decoupling means the separation of cooling and ventilation tasks by using separate dedicated outdoor air system (DOAS) and parallel air-conditioning system. It is found that among other available technologies, vapor-absorption (VA)-based systems are potential candidates towards the enhancement of energy-related performance. Tarsitano et al. [6] studied a solar powered absorption system for residential buildings. They examined the energy saving potential, economic analysis, and CO₂ reduction potential of the system. Xu and Wang [7] performed a comparative analysis of air-cooled absorption air-conditioning system with different configurations to optimize the COP of the system. In this direction, Singh and Das [8] done a simulation study on a solar and natural gas incorporated VA-based air-condition system and suggested various operating conditions to ensure better energy performance. They also [9] studied the performance of indirect evaporative cooler (IEC) and desiccant assisted VC building air-conditioning system for warm and humid climate. A modification using IEC and sensible heat recovery wheel was also reported [10].

From the above literature analysis it is observed that, significant work has been carried out in VC and VA-based cooling technologies, but, their comparative performance with desiccant and IEC for hot-dry and composite climates seems unavailable. It is not always necessary that VA-based system will be energy efficient due to space constraints and unavailability of sufficient heat energy. So, the only possible solution to address these constraints is to use an auxiliary heater operated by electricity or any high grade energy (based on diesel or petrol). This can result in more electric energy consumption. This study therefore, adopts energy performance analysis of an air-conditioning system using EnergyPlus simulations considering two different designs/configurations.

2. Building description and methodology
In this work, as per the space availability, a small building of total floor area 400 m² (20 m × 20 m) as shown in Fig. 1 is adopted for the analysis. The ceiling height of the building is 3.1 m. Building geometry is imported in the EnergyPlus simulation platform [11]. EnergyPlus software is an open source building energy simulation tool issued by the U.S. department of energy. In order to ensure the agreement of the present building construction with the available codes and references, a comparison is shown in Table 1. The reference values specified by the energy conservation building code (ECBC) [12] and national renewable energy lab (NREL) [13] are used for evaluation. The comparison is done on the basis of overall heat transfer coefficient, $U$, sensible heat gain coefficient, $SHGC$, and visible light transmittance ($VLT$). A satisfactory agreement between the attained and the reference values is highlighted. In this study two different climatic zones are considered: hot-dry and composite climates. For the building under consideration, occupancy density is 9 m²/person, light power density is 10 W/m², electric equipment power density is 75 W per person and ventilation requirement is $9.43 \times 10^{-3}$ m³/s for each person. Description of systems layout is discussed further.

![Figure 1. Schematic layout of the present building](image-url)
Table 1. Validation study of the present building construction

| Constructional details | Achieved parameters | Reference parameters [12, 13] |
|------------------------|---------------------|-------------------------------|
| Building wall          | $U = 0.421 \text{ W/(m}^2\text{K)}$ | $U = 0.440 \text{ W/(m}^2\text{K)}$ |
| Building roof          | $U = 0.426 \text{ W/(m}^2\text{K)}$ | $U = 0.409 \text{ W/(m}^2\text{K)}$ |
| Window glass           | $U = 3.01 \text{ W/(m}^2\text{K)}$ | $U = 3.30 \text{ W/(m}^2\text{K)}$ |
|                        | $VLT = 0.749$       | $VLT = 0.76$                  |
|                        | $SHGC = 0.264$      | $SHGC = 0.25$                 |

2.1. Methods of operation

2.1.1 Configuration 1: In this configuration, a VC system with a separate DOAS consisting desiccant material is modeled as shown in Fig. 2. The system is designed to maintain a desired level of thermal comfort all over the year. The DOAS is responsible to meet mainly the latent thermal load, whereas, parallel VC system addresses the remaining sensible and latent thermal load of the building. EnergyPlus solves various heat transfer equations for each component related to the system. For maintaining the necessary building thermal comfort, the VC system is designed to offer cold water at 7 °C [14] to the cooling coil. This supplies cool and dehumidified air inside the building space at 15°C and 0.008 kg/kg of dry air. Desiccant (usually silica gel) inside the DOAS absorbs moisture from the ambient air, whereas, the refrigerant’s temperature in the VC system is below the dew-point temperature of air, that condenses the moisture in air on the cooling coil. Therefore, in this manner, humidity within the building is controlled. In this configuration, solar collector system delivers the heat energy for regenerating desiccant material. Electricity operated auxiliary water heater is also used here to address the irregularity associated with the solar energy. As well-known, in the desiccant material, air temperature is increased up to 45 °C due to the process of chemical dehumidification. This high temperature dehumidified air cannot be delivered directly inside the building space. In this point of view, an IEC is provided to lower air temperature after passing through desiccant material up to 30 °C to supply it within the room. The validation of the installed VC system with the available reference building model [11] for hot-dry climate condition is presented in Table 2. It is worth to mention here that the reference building is of 1000 m² [11], thus, for the comparison purpose, the parametric values of the same are scaled down to 400 m² for evaluating it with the present building.

Figure 2. System layout for configuration 1 of air-conditioning
2.1.2. Configuration 2: In this configuration, a VA system is used in the place of VC system of the configuration 1 (Fig. 3). The DOAS including IEC are also same here. In this configuration, heat energy should be supplied at the generator side for proper functioning of the VA system. In the present analysis, the necessary heat energy is accomplished with the aid of biomass-based boiler of 60 kW. As there is abundant availability of biomass in form of food waste, cattle wastes, crop and agriculture residue, etc., biomass is used here as a source for generating the biogas. This generated biogas is used as a fuel inside the biomass-based boiler. The boiler is designed to deliver hot water at 80 °C to the generator end of the VA system. For sustaining the given thermal comfort, other components of this configuration are the same as configuration 1. In configuration 2, top roof area of around 300 m² is used for the installation of solar collectors to regenerate the desiccant. Therefore, the necessary heat energy requirement in the generator side has to be sustained by boiler system. This is because the available/vacant roof area of 100 m² will not be sufficient to meet the necessary heat load through solar collectors.

| S. No. | Parameters                        | Present study   | Reference study | Error % |
|-------|-----------------------------------|-----------------|-----------------|---------|
| 1     | Total heat gain in building       | 33928 kWh       | 31841 kWh       | 6.1     |
| 2     | Air system cooling energy         | 32443 kWh       | 32908 kWh       | 1.4     |
| 3     | Fan power                         | 5037 kWh        | 5537 kWh        | 9.9     |
| 4     | Total energy consumption          | 32139 kWh       | 29180 kWh       | 9.2     |

Figure 3. System layout for configuration 2 of air-conditioning

3. Results and discussion
Simulations are performed for both the discussed configurations under hot-dry and composite climatic conditions. Variable environmental circumstances affect the system performance in terms of energy consumption and COP. Figure 4a demonstrates the hour by hour details of the locations’ outside air temperature within a given year. The inside air temperature and humidity ratio achieved within the building by the air-conditioning system is also presented (Fig. 4b). EnergyPlus simulations are
performed for a whole year in order to sustain the thermal comfort around a specified level. From Fig. 4b, it is observed that within the air-conditioned space, the temperature is retained in the range 19°C - 26°C.

**Figure 4.** (a) Hourly variation of outdoor air temperature for both climates (b, c) Maintained indoor temperature and humidity for hot-dry and composite weather, respectively.
Figure 5 presents the yearly electric energy utilization pattern for the two weather conditions. In Fig. 5a the energy utilization outline pertains to hot-dry climate zone. From Fig. 5 it is well-highlighted that the total energy outflow occurring in a year for configuration 1 is more as compared to that relating to configuration 2. From the analysis, net electricity consumed within a year for hot and dry climate zone is found as 32139 kWh and 17171 kWh in configurations 1 and 2, respectively. Major reduction in electricity requirement for configuration 2 is due to the usage of VA system. However, in configuration 2, pumps consume more power than configuration 1. This is because, in configuration 2, one additional pump is provided to pass the hot water from biomass-based boiler to the generator inlet of the VA system. In configurations 1 and 2, the energy consumed in electric water heater is because of the incapability of the solar collector system to fulfil the energy requirement, particularly during adverse environmental conditions occurring in a year.

Figure 5. Annual electric energy utilization details (a) hot-dry weather (b) composite weather

For the composite weather (Fig. 5b), the yearly energy consumption for configuration 1 is 29047 kWh and the same for configuration 2 is 15644 kWh. From Fig. 5 it is well-observed that the net electricity consumed in both the configurations is lesser for the composite weather. This is due to the environmental conditions of these two locations. From the present observations, it is observed that for
the hot-dry weather, configuration 2 results in 46.57% electric energy savings than configuration 1. Furthermore, for the composite weather, this value is around 46.14% that is ascribed due to the difference in environmental conditions.

Figure 6 shows the yearly rate of heating delivered by the solar collector, electric heater and biomass-based boiler systems for both the weather zones. In both the configurations, heat energy supplied through the solar collector system is used for regenerating the desiccant material, whereas, biomass-based boiler is used for meeting the heating requirement in configuration 2 only. From this figure, it can be perceived that the heat energy delivered through solar collectors in composite climate is lesser than that supplied in the hot-dry climate. Moreover, the heating supplied by the biomass-based boiler in hot-dry climate is comparatively more than that in the composite climate, which indicates that the thermal load removed by the system in hot-dry climate is more than that removed in composite climate.

**Table 3** presents comparison between the $COP$ of VC system (configuration 1) and VA system (configuration 2). The study has been done for both the climate zones. From the table it is noticed that $COP$ of both the systems is more for composite climate. This is because thermal load removed and the electricity requirements are lesser in the composite weather than those relating to hot-dry weather. The $COP$ of VA system is defined as the ratio of the cooling load to the heat load supplied to the VA generator (neglecting pump work). However, for the VC system, the $COP$ is defined as the ratio of cooling load to the compressor work. For a given cooling load, the electricity (a high grade energy) requirement is of lesser magnitude than the heat energy (a low grade energy). Therefore, $COP$ of VC system is always higher than the VA system [15]. However, VA system is preferable to use the abundantly available solar thermal and waste heat resource and thereby saving the high grade electric energy.

| System          | Hot-dry weather | Composite weather |
|-----------------|-----------------|-------------------|
| $COP$ (VC system) | 2.73            | 2.77              |
| $COP$ (VA system) | 0.54            | 0.55              |

4. Conclusions
The present study shows the influence of using desiccant-assisted ventilation in vapour-compression (VC) and vapour absorption (VA) based air cooling systems for hot-dry and composite weather conditions. In present study, solar collectors supply heat energy to the desiccant side, whereas
A biomass-based boiler system is provided to meet the \( VA \)-system requirements. Electricity based heat is used only for contingency purpose to address any interruption in the availability of solar and bio energy. For the present objective, EnergyPlus simulations are done for a complete year. From the present study, it is shown that the usage of \( VA \) along with desiccant driven system offers more energy savings with respect to the \( VC \) driven system. Compared to \( VC \)-based system, electric energy saving potential of \( VA \)-operated system for hot-dry weather condition is 46.57%, and the same for composite weather is nearly 46.14%. Apart from this, it is also concluded that the \( VA \) system would be more beneficial for hot-dry weather in comparison with the composite weather.

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