# Simple relationships for the COP of AC systems operating at very high ambient temperatures

**Key words:** AC system, coefficient of performance, hot climate, regression relationship

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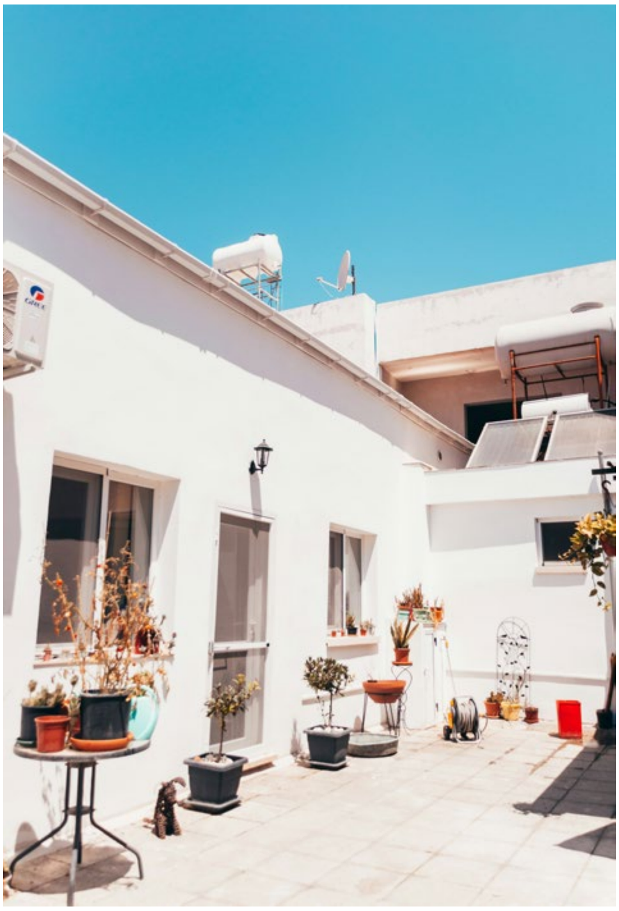
Experimental results from literature concerning the performance of AC systems operating with different refrigerants (R22, R410A, R290, R32, DR3, ARM20B, N20B, R444B, DR55, ARM71A and R447A) at very high ambient temperature have been collected and good accuracy regression relationships are derived for the COP of these AC systems in terms of the difference between the outdoor and indoor temperatures. These relationships may be used as generic information during studies involving AC systems in hot climates.

The performance of air conditioning (AC) systems operating with different refrigerants has been studied in many papers. However, relatively few papers treated the coefficient of performance (COP) of specific AC systems operating at very high outdoor temperature (for a review see Alawadhi and Phelan, 2022). This lack of information makes difficult the elaboration of feasibility studies for building climatization in places with tropical climates or during very hot summer days in locations with temperate or continental climates. Generic information about AC systems performance would be valuable in these cases and providing such generic information in an easy-to-use way is the objective of this short report.

Experimental results from the small number of papers treating the performance of AC systems operating with different refrigerants at very high ambient temperature are collected. The focus is on R22 and R410 but several low GWP substitutes of these refrigerants are also considered. Regression relationships are proposed



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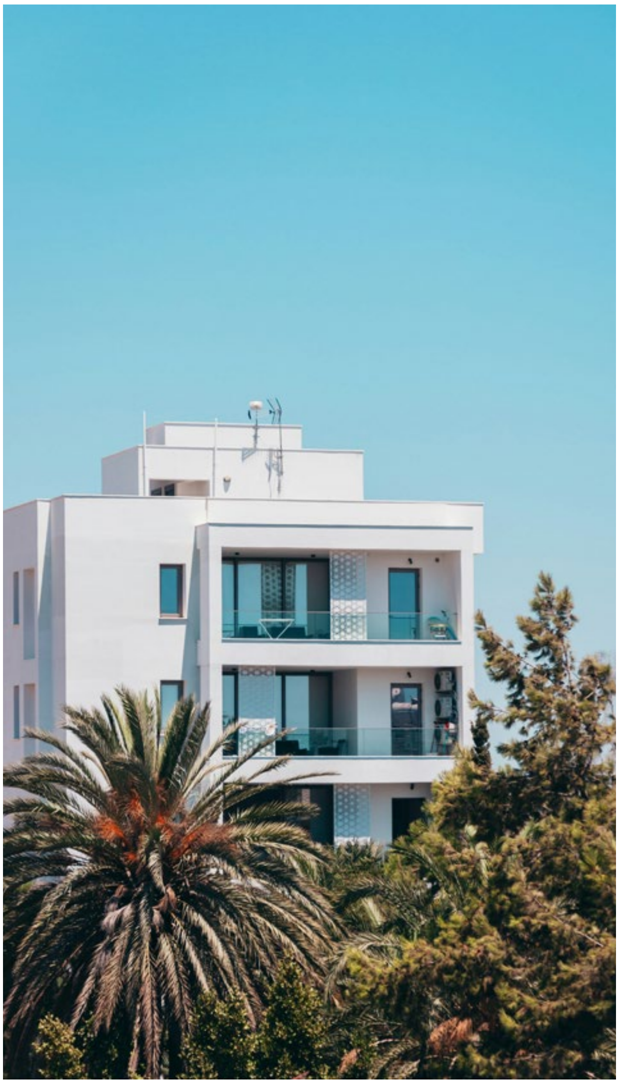
for the COP of these AC systems in terms of the difference between the outdoor and indoor temperatures. Of course, the COP of AC systems depends on many specific details, such as compressor efficiency, the usage or not of electronic expansion valves, the heat transfer effectiveness and cleanliness of the condenser and evaporator and the refrigerant charge amount. However, these relationships may be useful as a first guess providing fast perspectives when preliminary or feasibility studies of building climatization in very hot climates are elaborated.

## Data collection and processing

Presently, R410A is the most popular refrigerant used for AC systems. However, due to its large GWP value, R410A is expected to be replaced in the future. R32 and R290 are lead candidates to replace R410A but other refrigerants are also tested in laboratories. The interest here is only on AC systems operating at high ambient temperature.



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We have digitized some of the experimental data presented in figures 3 and 4 of Payne and Domanski (2002), showing the dependence of COP on the outdoor temperature $T_{outdoor}$ for AC systems operating with refrigerants R22 and R410A, respectively. One of the objectives of Payne and Domanski (2002) was to measure the performance of the R410A system when the condenser operates above the critical point. Therefore, the tests were extended to 68.3 °C ambient temperature by using a customized compressor with internal safeties removed and having a more powerful electric motor than the compressor used for the R22 system. Measurement uncertainty at 95 % confidence level is shown in table 1 of Payne and Domanski (2002) for temperatures, pressures, pressure difference, temperature difference, dew-point temperature, and power. The 95 % relative uncertainty in COP values varied from 3.5 % to 5.4 %.

Also, we have digitized data presented in Figure 12 of Joudi and Al-Amir (2014). Two split type air conditioners were tested by these authors. The first type, with a nominal cooling capacity of 1 TR (3.517 kW), is model TAC12 manufactured by Concord company from Lebanon and the second type, with a nominal cooling capacity of 2 TR (7 kW), is model EL-26ITERH manufactured by Denka company from Korea. The refrigerants used in these two AC systems are R22, R290, R407C and R410A. An uncertainty analysis is performed in section 6 of Joudi and Al-Amir (2014) and the uncertainty of the COP data is presented in table 3 of Joudi and Al-Amir (2014). In case of the 2 TR system the uncertainty is ±5.32%, ±6.52%, ±4.9% and ±5.54% for R22, R407C, R410A and R290, respectively, while for the 1 TR system the uncertainty is ±4.28%, ±3.23%, ±6.22% and ±3.55% for R22, R407C, R410A and R290, respectively.

Table 4 of Shen et al. (2016) presented experimental data concerning the dependence of COP on outdoor temperature for R22 and several low GWP replacements of R22 (R290, DR3, ARM20B, N20B and R444B). Also, table 5 of Shen et al. (2016) presented experimental data for R410A and several low GWP replacements of R410A (R32, DR55, ARM71A and R447A). We have digitized the data of tables 4 and 5 of Shen et al. (2016). Information about the uncertainty of these experimental data is presented in the preliminary report by Abdelaziz et al. (2015). The air-side COP for R22, N20B, DR3, ARM20B, R444B and R290 had an uncertainty of ±2.4% (page xvi of the report) while the air-side COP for R410A, R32, DR55, R447A and ARM71A had an uncertainty of ±1.6% (page xviii of the report).

The collected experimental data are presented in **figures 1 to 6**. Operation of an air conditioner at elevated ambient temperatures inherently results in a lower coefficient of performance, as expected. For low ambient temperature, the early study of Payne and Domanski (2002) shows higher COP values for R22 and R410A than the more recent results of Shen et al. (2016) (**Figure 1 and 2**). This may be partially explained by the significant difference in the size of the experimental equipments (the cooling capacity in Payne and Domanski (2002) is 11.78 kW and 11.8 kW for R22 and R410A, respectively, while the corresponding values in Shen et al (2016) are 5.0 and 3.98 kW, respectively – see tables ES4 and ES7, respectively, of Abdelaziz et al. (2015)).

The experimental results of Joudi and Al-Amir (2014) and Shen et al. (2016) are quite similar in magnitude for the whole range of variation of the outdoor temperature, for R22 (**Figure 1**), R410A (**Figure 2**) and R290 (**Figure 3**).

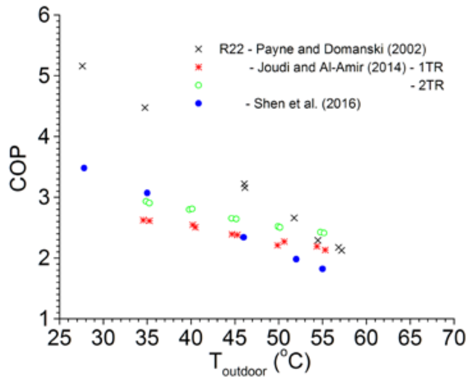


**Figure 1.** Dependence of COP on outdoor temperature $T_{outdoor}$ for AC systems operating with R22.

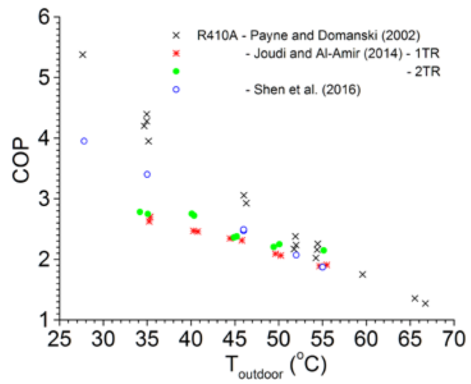


**Figure 2.** As Figure 1 for R410A.

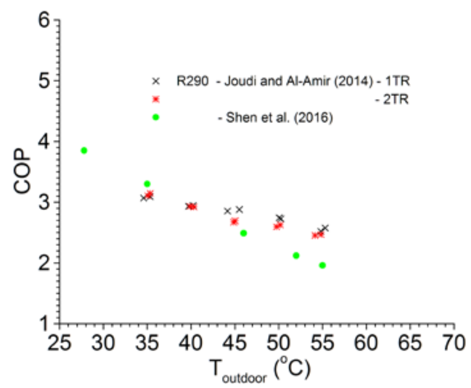


**Figure 3.** As Figure 1 for R290 as a candidate to replace R22.

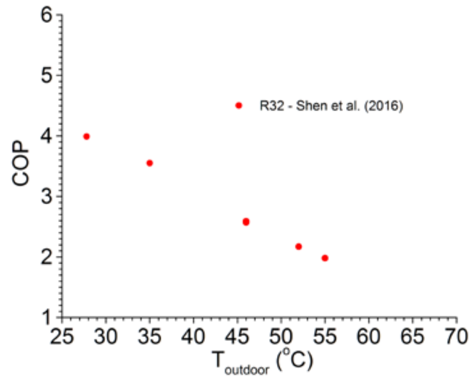


**Figure 4.** As Figure 1 for R32 as a candidate to replace R410A.

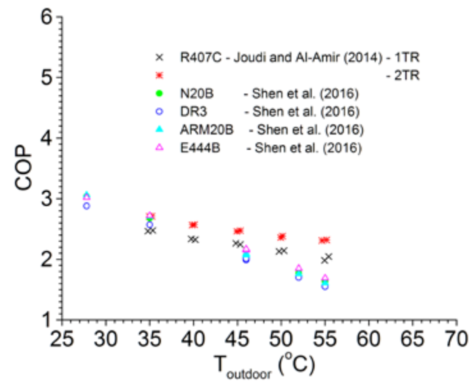


**Figure 5.** As Figure 1 for candidate refrigerants to replace R22 (DR3, ARM20B, N20B and R444B).

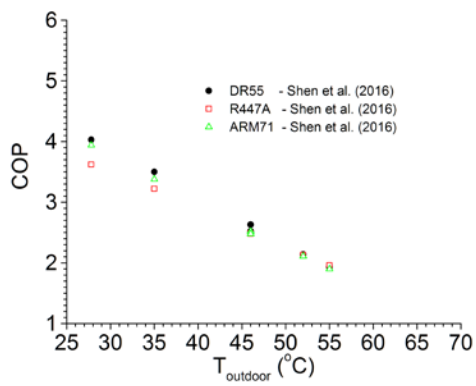


**Figure 6.** As Figure 1 for candidate refrigerants to replace R410A (DR55, ARM71A and R447A).

*Table 1.* *The COP of several refrigerants as a function of the temperature difference $\Delta T$ (in °C) between the outdoor and indoor temperatures, $T_{outdoor}$ and $T_{indoor}$, respectively. The coefficient of determination $R^2$ is also shown. [A] Payne and Domanski (2002); [B] Joudi and Al-Amir (2014); [C] Shen et al. (2016).*

| Number | Refrigerant | Reference | Equation | a | b | R2 |
|---|---|---|---|---|---|---|
| 1 | R22 | [A] | COP = $a + b\Delta T$ | 5.2584 | -0.1042 | 0.997 |
| 2 | | [B]- 1TR | COP = $(a + b\Delta T^{1.5})^{-1}$ | 0.3609 | 0.0006 | 0.977 |
| 3 | | [B]– 2TR | COP = $(a + b\Delta T)^{-1}$ | 0.3044 | 0.0036 | 0.994 |
| 4 | | [C] | COP = $(a + b\Delta T^{1.5})^{-1}$ | 0.2831 | 0.0019 | 0.991 |
| 5 | R410A | [A] | COP = $a + b\Delta T$ | 1.7273 | -0.0350 | 0.989 |
| 6 | | [B]- 1TR | COP = $(a + b\Delta T^{2})^{-1}$ | 0.3563 | 0.0001 | 0.988 |
| 7 | | [B]– 2TR | COP = $(a + b\Delta T^{1.5})^{-1}$ | 0.3274 | 0.0009 | 0.903 |
| 8 | | [C] | COP = $a + b\Delta T$ | 4.0542 | -0.0852 | 0.993 |
| 9 | R290 | [B]– 1TR | COP = $(a + b\Delta T^{1.5})^{-2}$ | 10.0554 | -0.0212 | 0.972 |
| 10 | | [B]– 2TR | COP = $(a + b\Delta T^{0.5})^{-1}$ | 0.1973 | 0.0380 | 0.980 |
| 11 | | [C] | COP = $(a + b\Delta T^{1.5})^{-1}$ | 0.2577 | 0.0018 | |
| 12 | R32 | [C] | COP = $(a + b\Delta T^{2})^{-1}$ | 0.2526 | 0.0003 | 0.990 |
| **Low GWP substitutes for R22** | | | | | | |
| 13 | R407C | [B]– 1TR | COP = $a + b\Delta T$ | 2.6819 | -0.0219 | 0.980 |
| 14 | | [B]– 2TR | COP = $(a + b\Delta T^{0.5})^{-1}$ | 0.2815 | 0.0276 | 0.994 |
| 15 | N20B | [C] | COP = $(a + b\Delta T^{1.5})^{-1}$ | 0.3253 | 0.0021 | 0.994 |
| 16 | DR3 | [C] | COP = $a + b\Delta T$ | 2.9728 | -0.0542 | 0.992 |
| 17 | ARM20B | [C] | COP = $a + b\Delta T$ | 3.1521 | -0.0592 | 0.989 |
| 18 | R444B | [C] | COP = $a + b\Delta T$ | 3.1195 | -0.0540 | 0.991 |
| **Low GWP substitutes for R410A** | | | | | | |
| 19 | DR55 | [C] | COP = $a + b\Delta T$ | 4.1449 | -0.0857 | 0.983 |
| 20 | R447A | [C] | COP = $(a + b\Delta T^{1.5})^{-1}$ | 0.2724 | 0.0017 | 0.992 |
| 21 | ARM71A | [C] | COP = $(a + b\Delta T^{1.5})^{-1}$ | 0.2506 | 0.0019 | 0.990 |

The performance of AC systems has been studied by various authors for different values of the indoor temperature. For instance, Payne and Domanski (2002) used an indoor temperature $T_{indoor}$ = 26.7°C during their tests for the AC systems operating with R22 and R410A. Joudi and Al-Asur (2014) performed their tests at $T_{indoor}$ = 25°C. Shen et al. (2016) performed experiments for six test conditions, characterized by the following outdoor temperatures $T_{outdoor}$: 27.8, 35, 46, 46, 52, and 55 °C, which are associated with the following indoor temperatures $T_{indoor}$: 26.7, 26.7, 26.7, 29, 29 and 29 °C, respectively.

The available experimental data has been systemized and condensed by using the following two-step procedure.

First, the COP is represented as a function of the temperature difference:

$$\Delta T \equiv T_{outdoor} - T_{indoor} \quad (1)$$

Second, the experimental data of **figures 1 to 6** show in general a monotonous decrease of COP in terms of $T_{outdoor}$. Therefore, it is expected that rather simple two-coefficient regression relationships COP($\Delta T$) may be successfully fitted to the data. **Table 1** shows the results obtained by using the software TableCurve2D (2002).

The coefficient of determination $R^2$ of the regression relationships in **Table 1** is greater than 0.9, showing good accuracy.

## Conclusions

Experimental results from literature concerning the coefficient of performance of AC systems operating with different refrigerants at high ambient temperature have been collected and good accuracy regression relationships are derived in terms of the difference between the outdoor and indoor temperatures. The paper constitutes an effort to consolidate existing experimental data and the relationships may be used as an educational resource or as generic information during feasibility studies involving AC systems in very hot climates.

## References

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