

大语言模型在制冷空调系统运维应用研究

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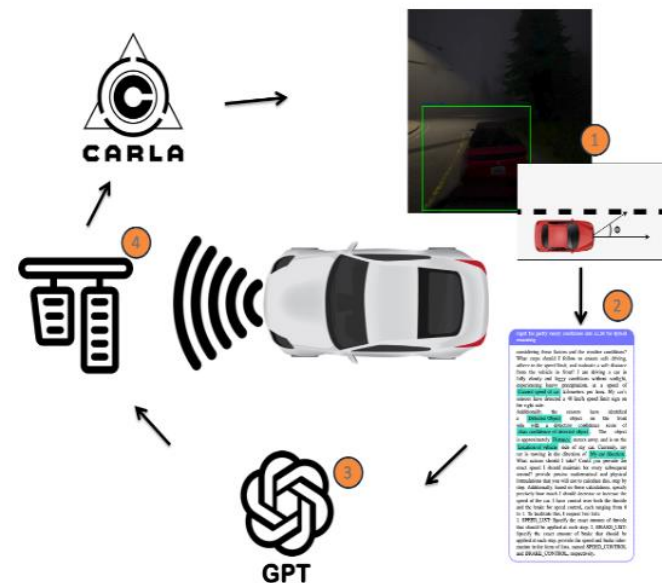
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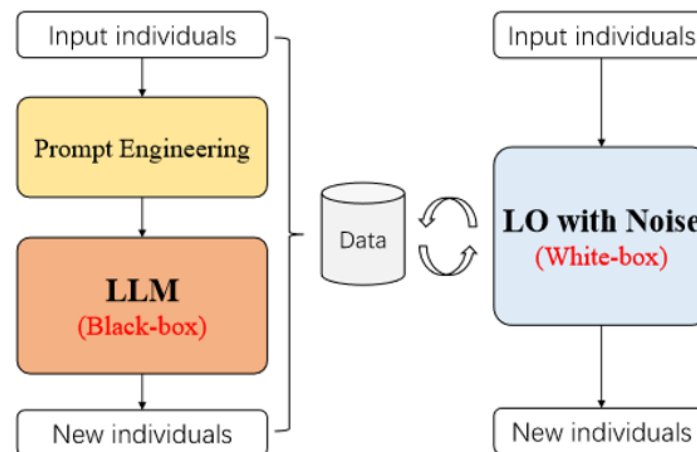
GPT-4等大模型是面向所有领域的通用化模型，自问世以来已经在数学、金融、医疗、自动驾驶等领域实现许多应用与突破。然而大模型是否具备**暖通领域知识**，能否支持暖通行业实现更强大的**通用化人工智能（AGI）**，目前仍旧未知

本文研究的关键问题：

- 如何评估大模型在暖通领域的知识水平？
- 大模型掌握的暖通知识能否支撑未来实现AGI？
- 大模型如何助力暖通领域未来的发展？



基于大模型的自动驾驶流程



基于大模型的多目标进化优化

大模型能力评估整体框架

大模型在暖通领域的评估测试

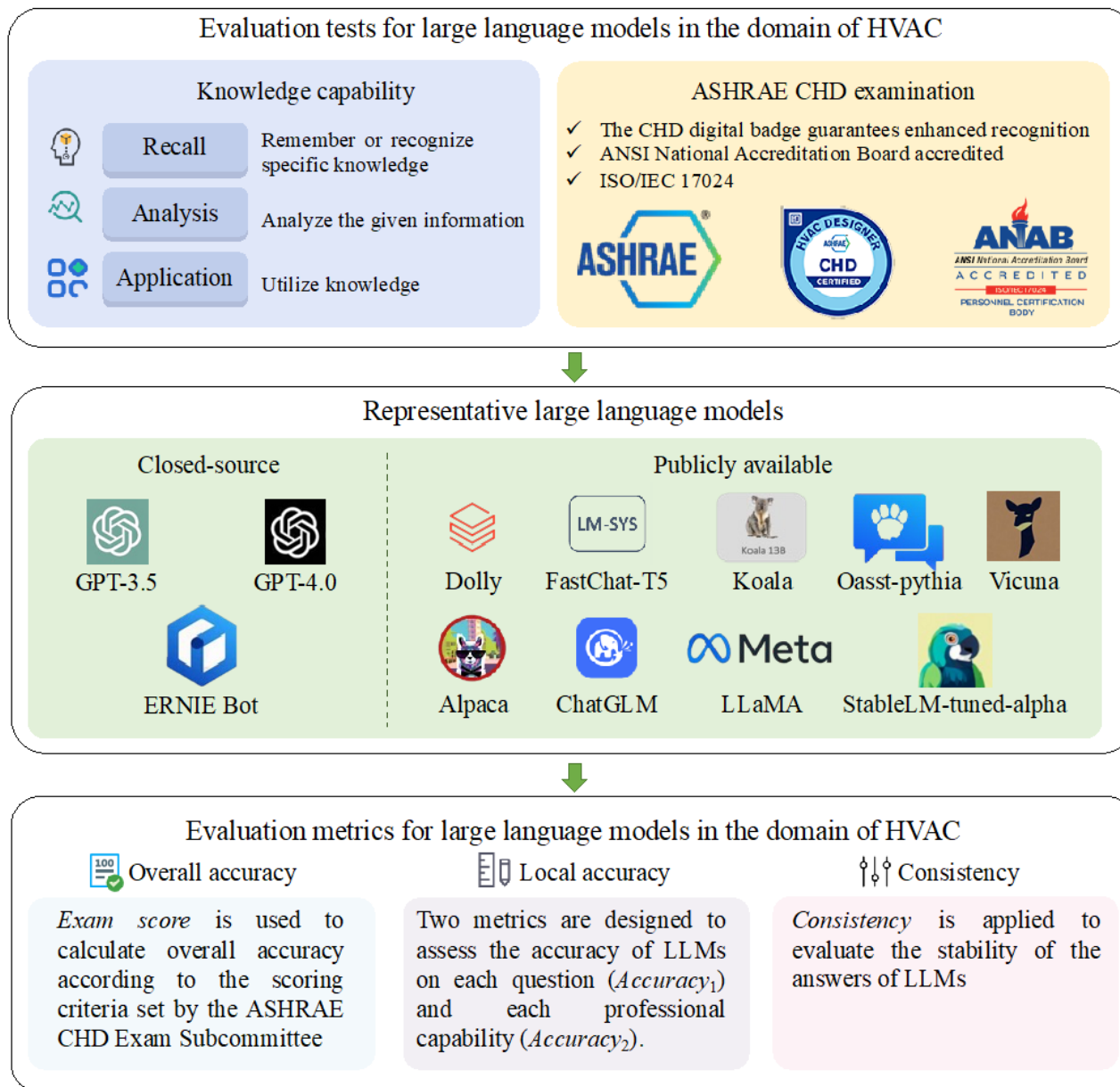
- 考查能力：知识储备、分析与应用
- 考试选择：ASHRAE CHD考试

选择具有代表性的大模型

- 闭源模型
- 开源模型

大模型在暖通领域能力的评价指标

- 总体准确率
- 局部准确率
- 回答一致性



暖通领域大模型能力评估框架

评估测试体系

3个维度

知识储备(50%)

记忆或识别特定知识的能力

分析能力(30%)

分析给定信息并作答的能力

应用能力(20%)

运用知识解决问题的能力

4种场景

系统设计

暖通设计的概念与术语

设计计算

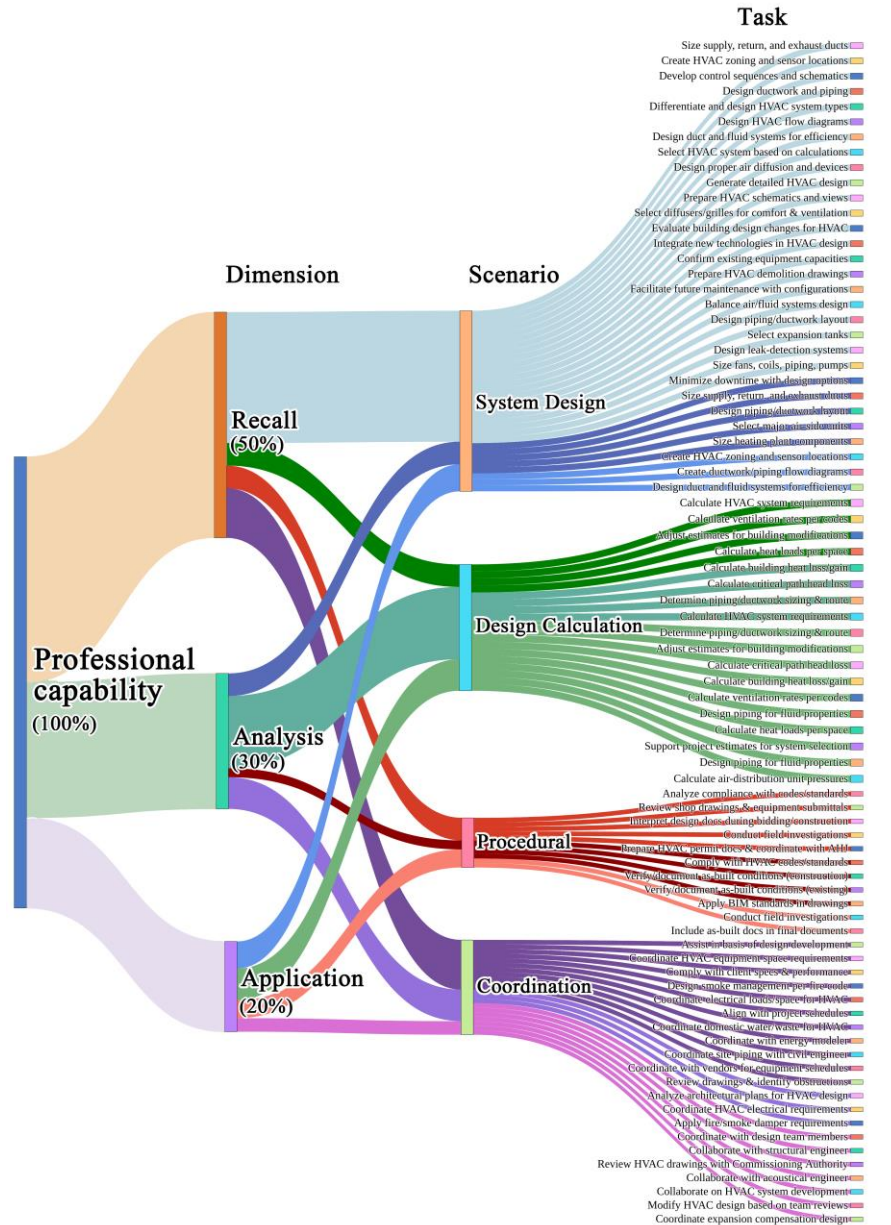
暖通设计计算

流程

暖通设计流程

协调

统筹多方合作



暖通专业能力评估测试涵盖的能力、场景和任务

暖通专业能力评估

ASHRAE CHD考试

ASHRAE Certified HVAC Designer(CHD)

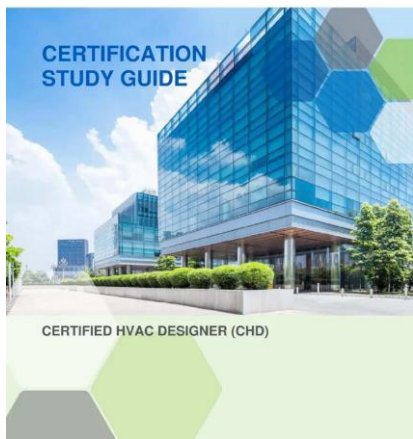
考试是一项对暖通空调设计人员要求较高的

综合性考试，由ANSI国家认可委员会认证。

它涵盖了对前述的三个能力、四种场景问题的

考查。采用ASHRAE CHD考试指南中的

100道单选题来评估大模型的知识能力。



ASHRAE CHD考试指南

Capability	Scenario	Task	Question
Recall	System Design	Design leak-detection systems	What is the allowable leakage in a piping installation? <input checked="" type="checkbox"/> A. 0% B. 0.5% C. 1%
	Procedural	Review shop drawings & equipment submittals	What does a system manual typically include? <input checked="" type="checkbox"/> A. current facility requirements B. design calculations <input checked="" type="checkbox"/> C. owner's project requirements
Analysis	System Design	Create HVAC zoning and sensor locations	What's the MOST accurate statement about the task of sequencing heating and cooling? <input checked="" type="checkbox"/> A. Avoid sequential use of cool outdoor air for heating and cooling in central fans. B. Implement simultaneous heating and cooling for humidity regulation. C. Choose zones and systems to minimize or eradicate simultaneous heating and cooling.
	Design Calculation	Calculate building heat loss/gain	What's the MOST accurate statement about estimating heat loss in entirely below-grade structures? <input checked="" type="checkbox"/> A. Treat all below-grade surfaces the same. <input checked="" type="checkbox"/> B. Use heat flow paths to determine steady-state ground surface heat loss. C. Exterior air temperature is vital for calculating heat loss.
Application	Design Calculation	Size heating plant components	Calculate the total pressure of a SWSI centrifugal fan, given the fan static pressure (4.80 in of water or 1194 Pa) and outlet velocity (2800 fpm or 14.2 m/s), for standard air at a specified speed. <input checked="" type="checkbox"/> A. 4.80 in of water (1194 Pa) B. 5.29 in of water (1316 Pa) C. 5.50 in of water (1369 Pa)
	Coordination	Collaborate with acoustical engineer	To maintain NC-40 office noise levels, an HVAC designer, collaborating with an acoustic engineer, should use a duct silencer due to excessive AHU supply fan noise. The BEST position for the duct silencer is <input checked="" type="checkbox"/> A. as near to the fan as feasible B. upstream of the first supply air device C. downstream of the fan, post the first elbow

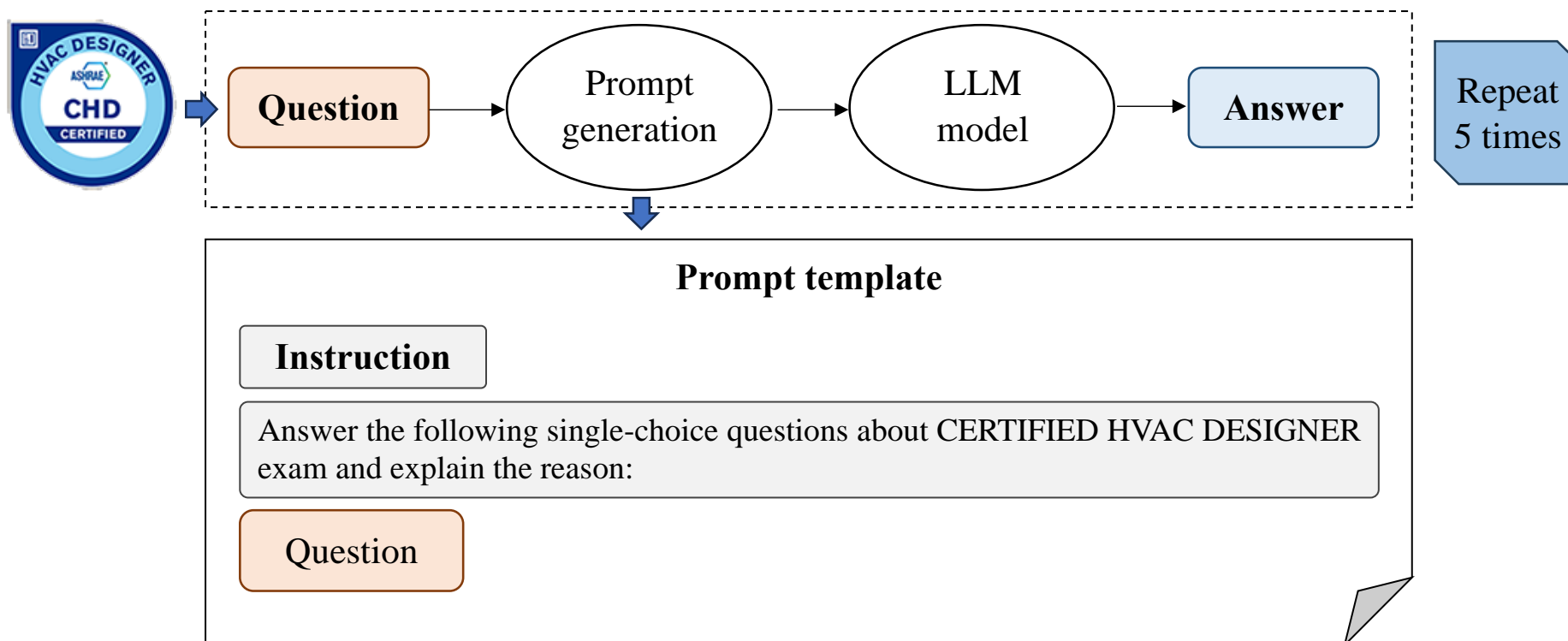
暖通空调领域大模型能力评估样题

□ 大模型测试流程

用提示词模板生成提示，模板由指示和问题两部分组成：

- 指示 (Instruction) : 说明大模型应完成的任务，即选出问题的答案并给出解释
- 问题 (Question) : 为ASHRAE CHD考试100道单选题中的某一题

考虑大模型回答的随机性和历史对话的影响，每个问题会在新的对话框中进行，并重复五次



大模型能力评估测试流程图

研究评估了12种开源/闭源大模型，并定义了三种评价指标

可访问性	模型名称	参数大小 (B)	预训练模型
闭源	GPT-3.5	-	GPT-3
	GPT-4.0	-	GPT-3.5
	ERNIE Bot	-	ERNIE 3.0
开源	LLaMA	13	-
	Alpaca	13	LLaMA
	Koala	13	LLaMA
	Vicuna	13	LLaMA
	Dolly	12	Pythia
	Oasst-pythia	12	Pythia
	FastChat-T5	3	FLANT5
	ChatGLM	6	GLM
	StableLM-tuned-alpha	7	LLaMA

评价指标

- **总体准确率：ASHRAE CHD考试题中正确的个数**

$$Exam\ score = \sum_{i=1}^m n_i$$

- **局部准确率：**

指标一：

大模型在每个问题上的准确性

$$Accuracy_{1,i} = \frac{Q_{C,i}}{Q_T}$$

指标二：

大模型在每种能力上的准确性

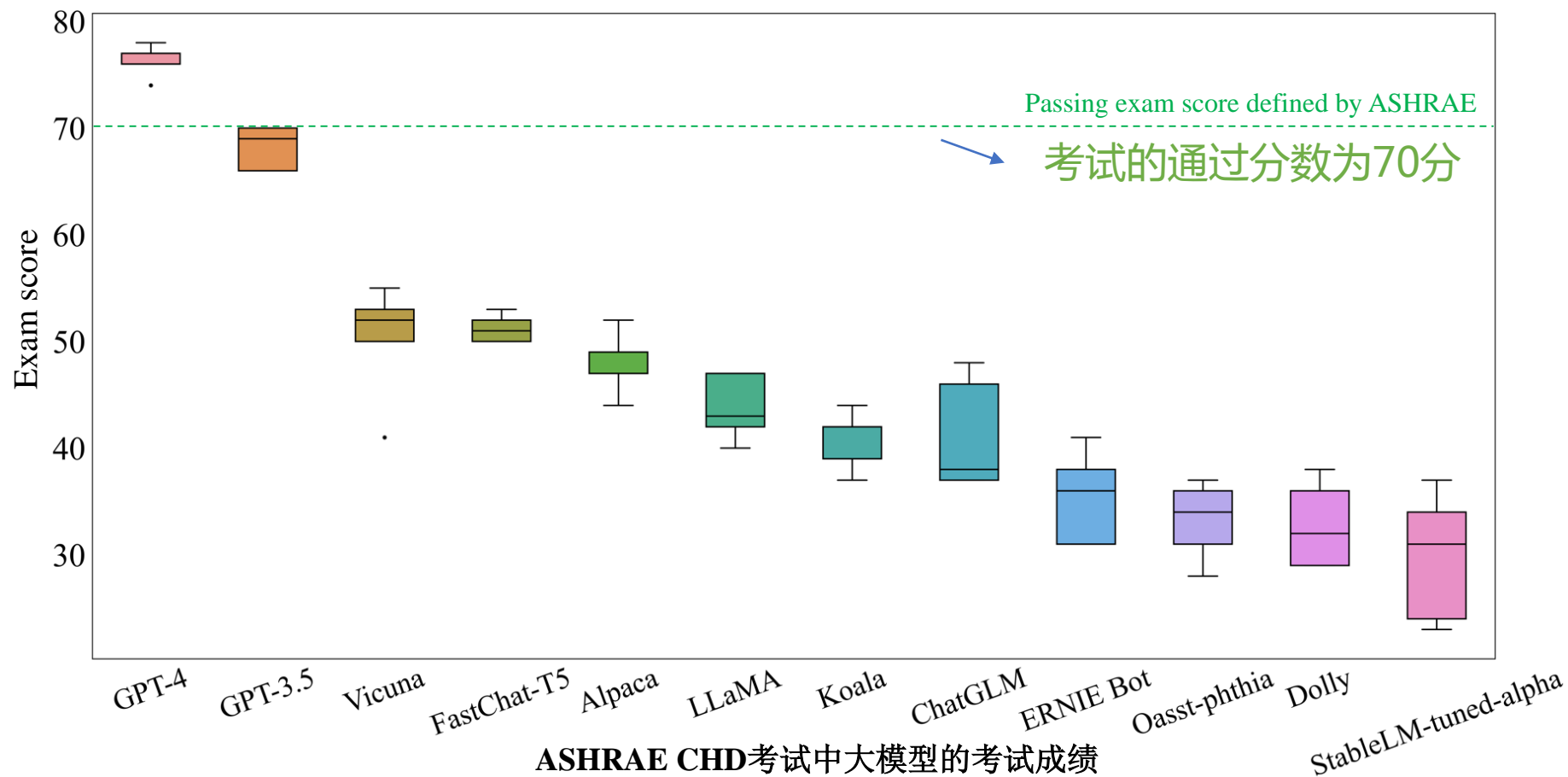
$$Accuracy_2 = \frac{\sum_{i=1}^m f_i}{m}$$

- **一致性：评估大模型回答的稳定性**

$$Consistency = \frac{\sum_{i=1}^m \frac{c_i}{Q_T}}{m}$$

为控制温度超参数的影响，模型的温度参数均设置为1.0

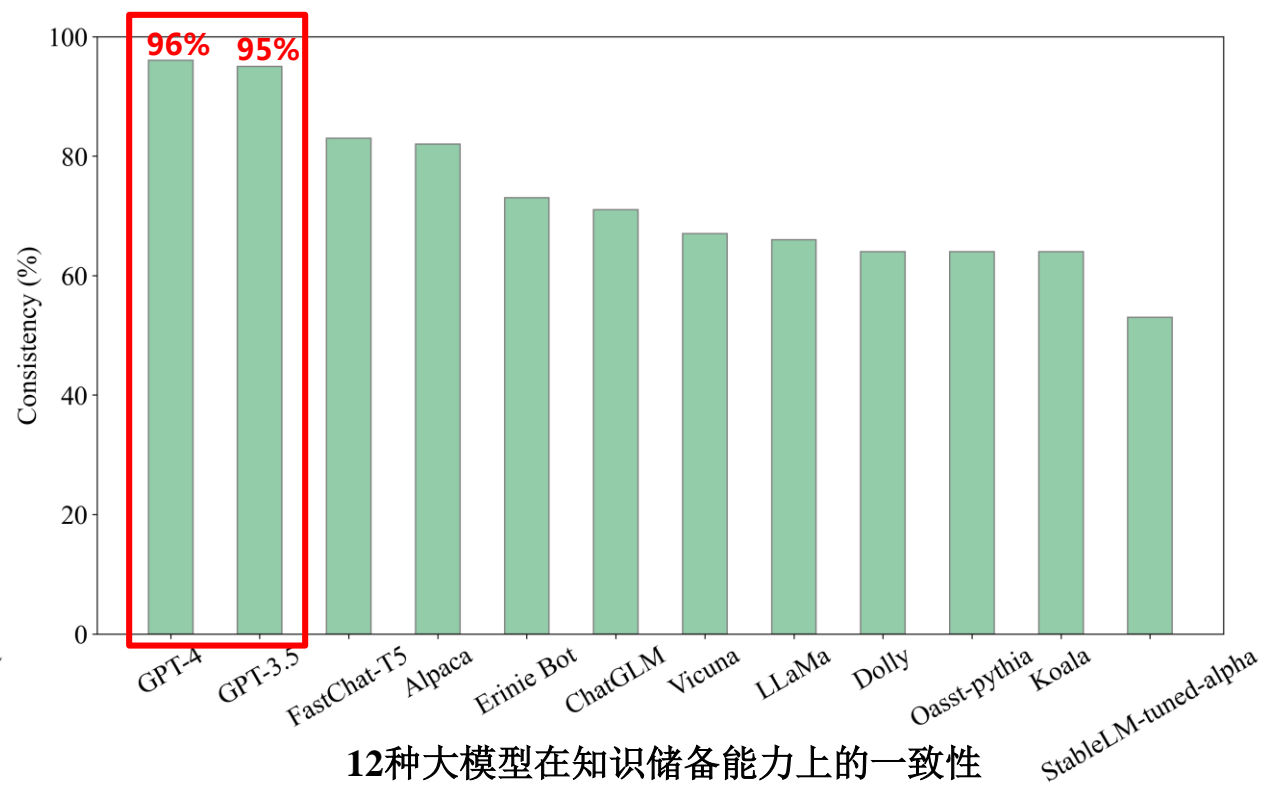
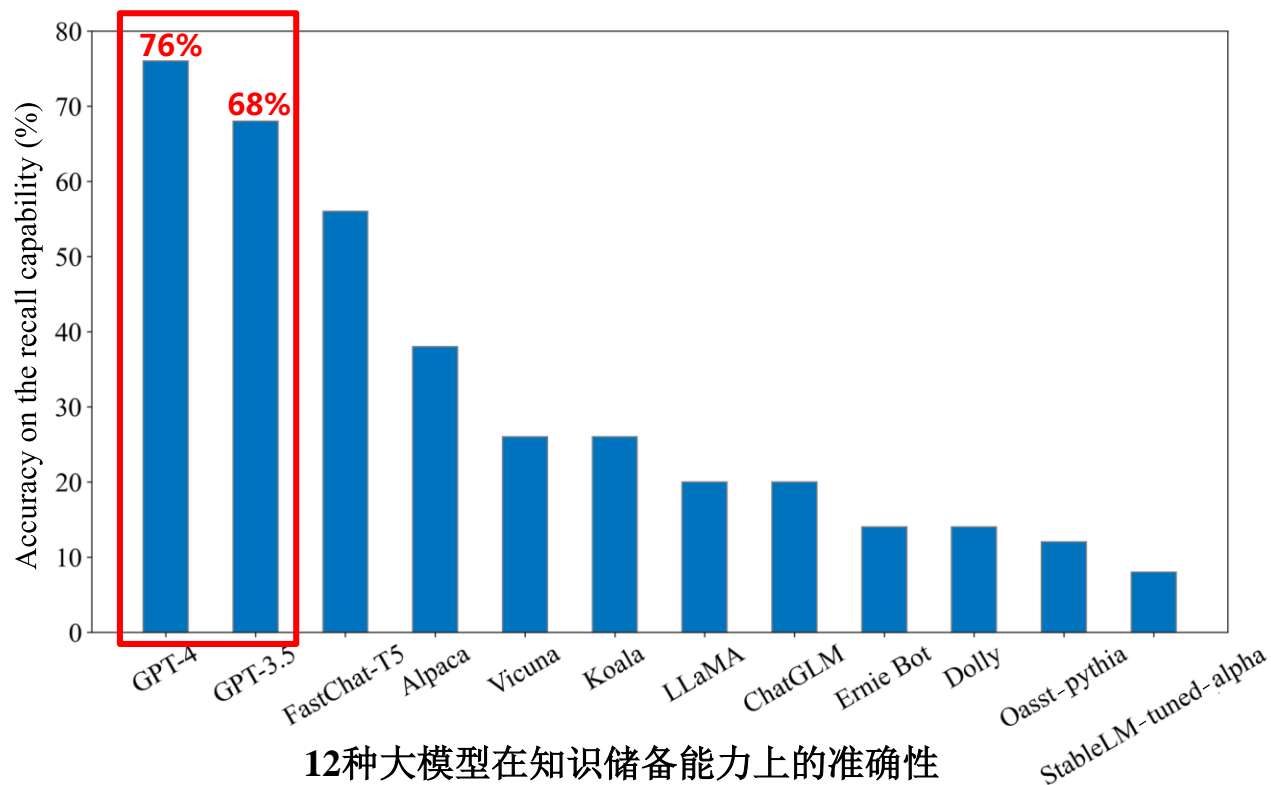
每个大模型进行五次测试，结果显示GPT-4和GPT-3.5是**唯一**通过ASHRAE CHD考试的大模型。
GPT-4分数在74-78分之间，**始终高于及格分数**；GPT-3.5通过了两次考试，其分数在66-70分之间



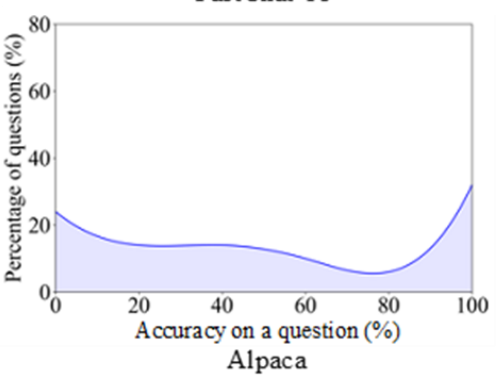
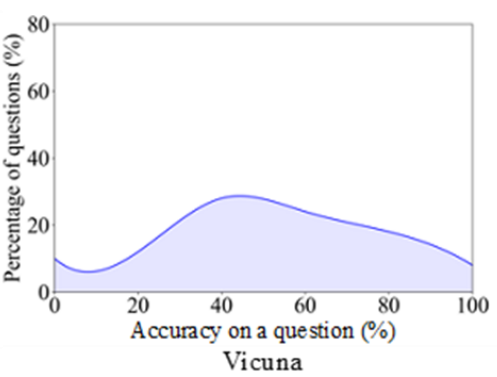
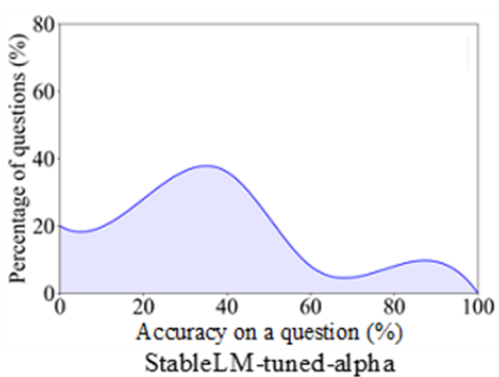
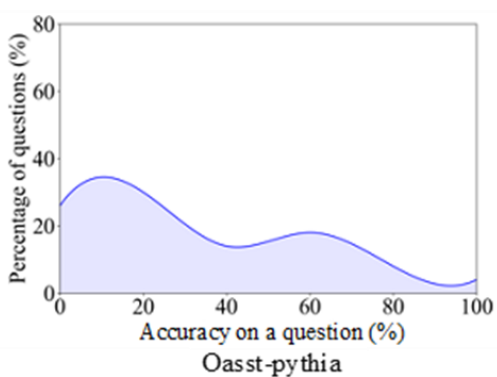
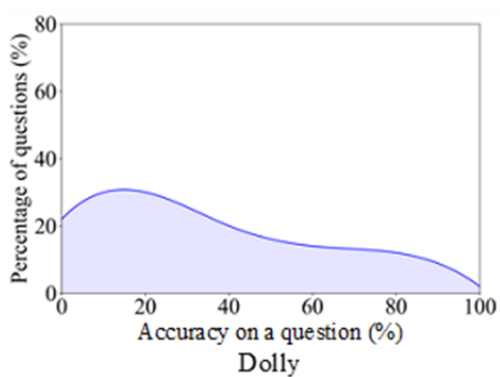
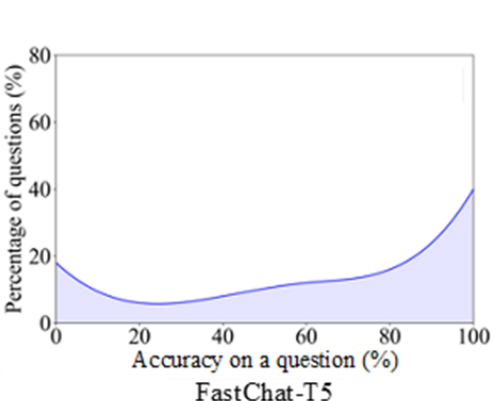
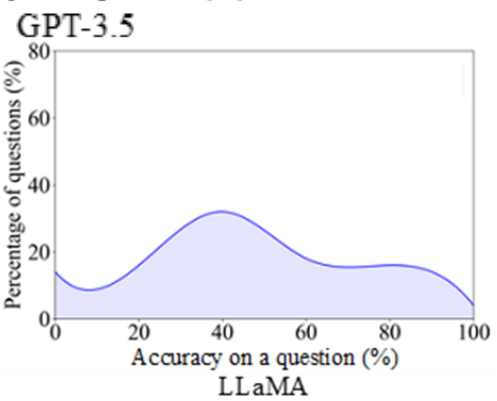
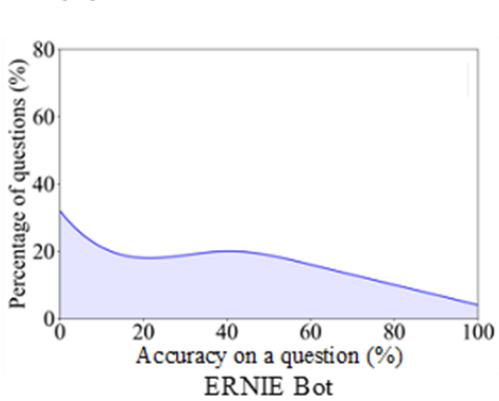
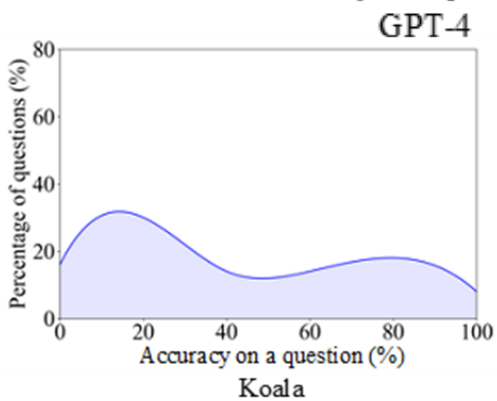
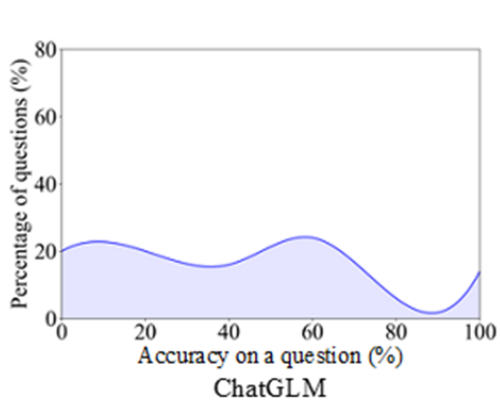
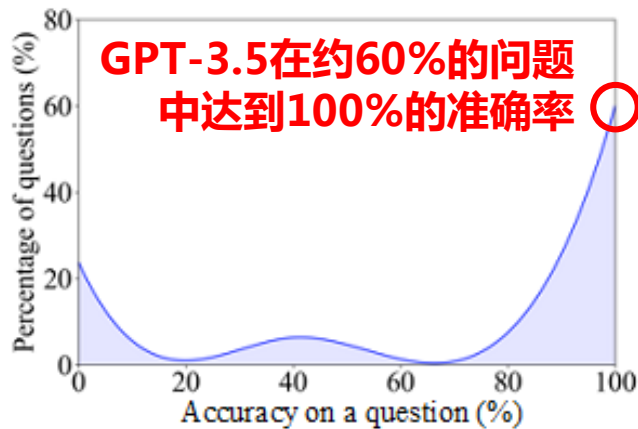
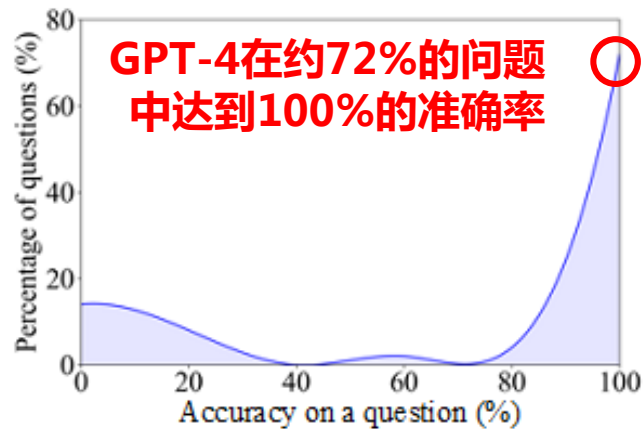
- 截至2022年12月，人类考生首次参加该考试的通过率为53%，相比之下GPT-4和GPT-3.5**超过了大约一半的人类考生**

● 大模型在知识储备能力上的对比

- GPT-4和GPT-3.5在知识储备能力上**准确性较高**，能够正确回答大部分与暖通空调相关的问题。其他大模型仍然缺乏领域知识
- GPT-4和GPT-3.5在知识储备能力上表现出**高度的一致性**，对于同一问题的答案基本一致，其他大模型稳定性和可靠性欠佳



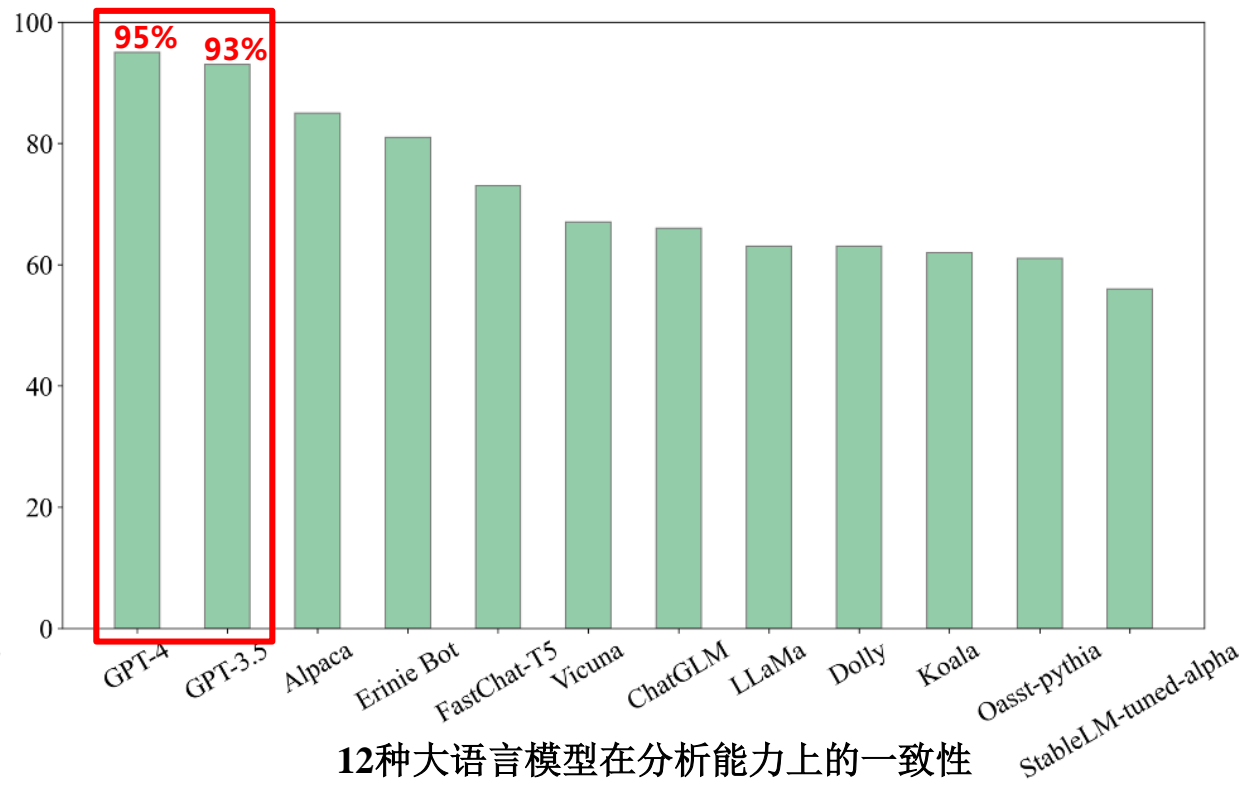
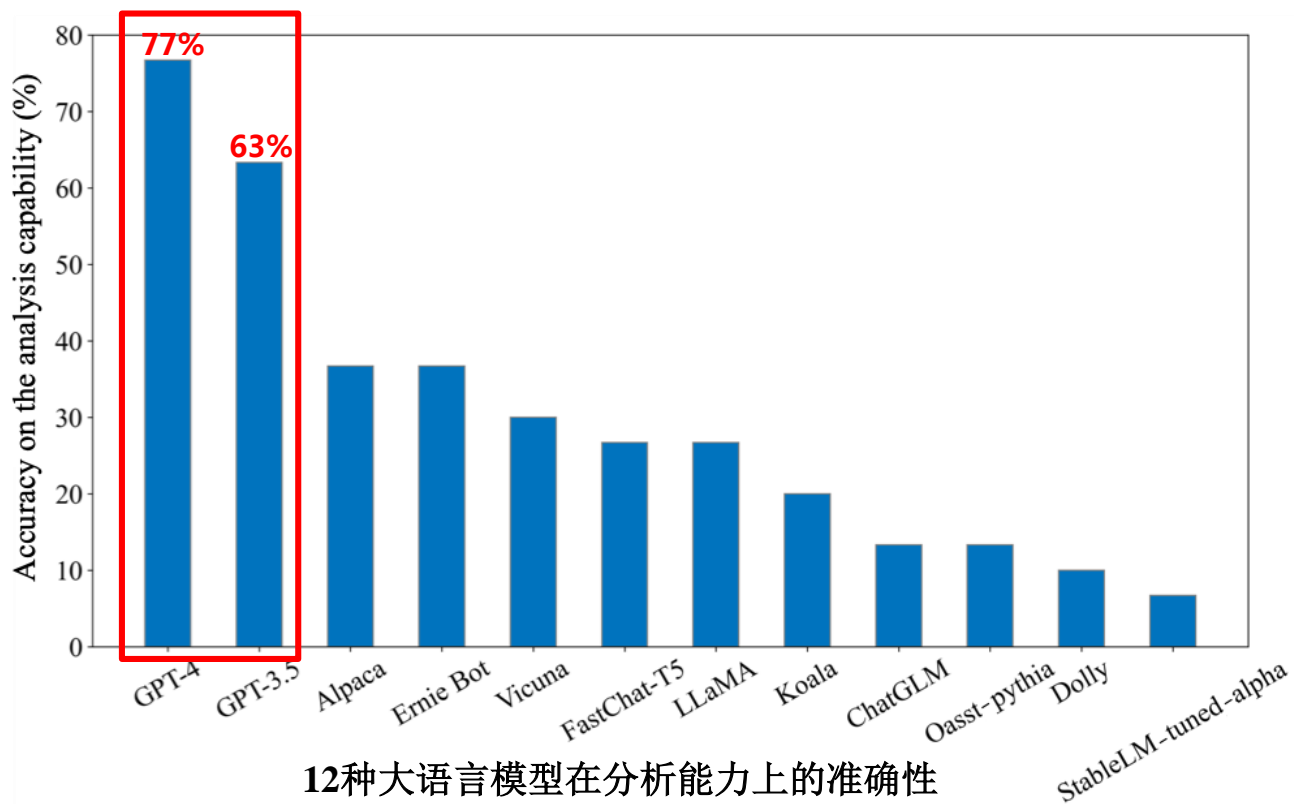
● 大模型在知识储备能力上准确率的对比



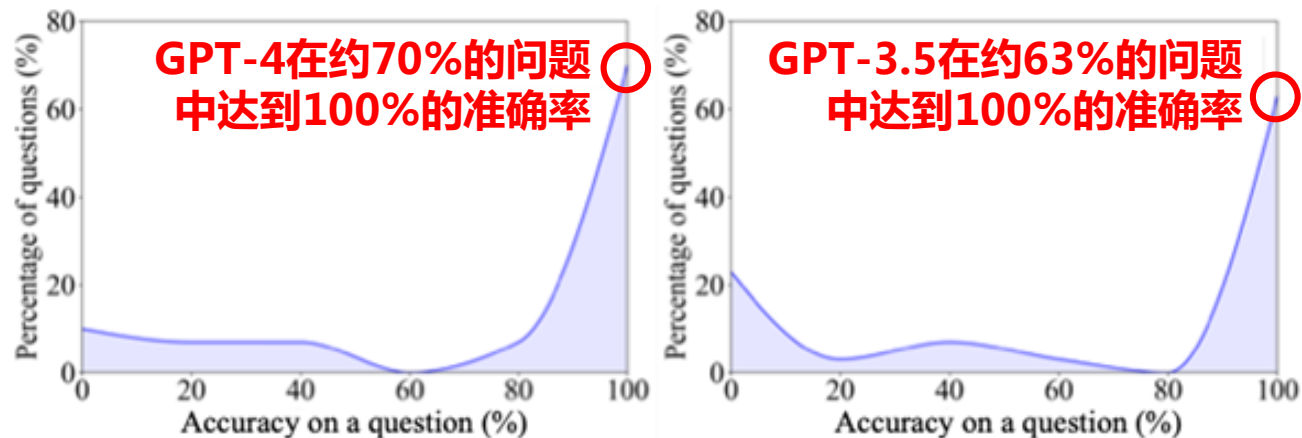
● 大模型在分析能力上的对比

- GPT-4在分析能力上的**准确性最高**，GPT-3.5在其之后，其余大模型对分析能力的准确性均明显下降

- GPT-4和GPT-3.5在分析能力上展现出**极高的一致性**，而其他模型则一致性较低

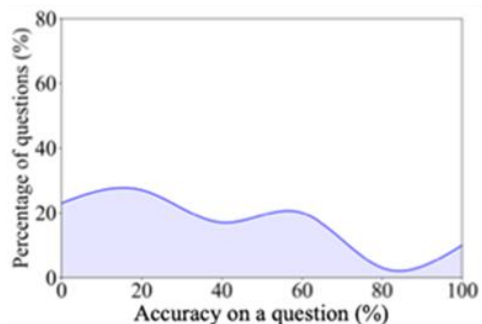


● 大模型在分析能力上准确率的对比

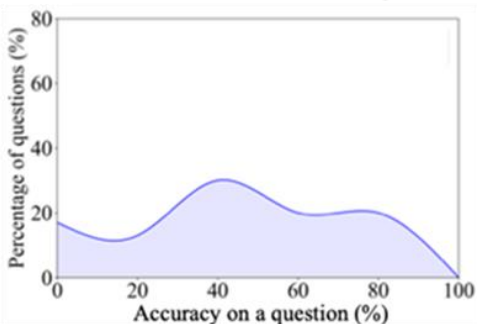


GPT-4

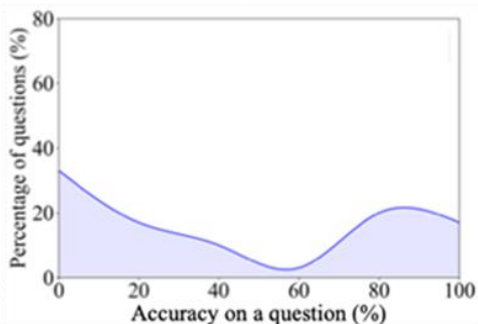
GPT-3.5



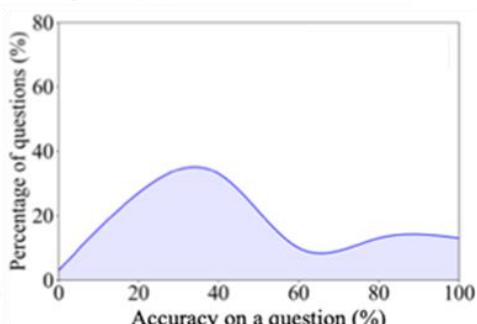
ChatGLM



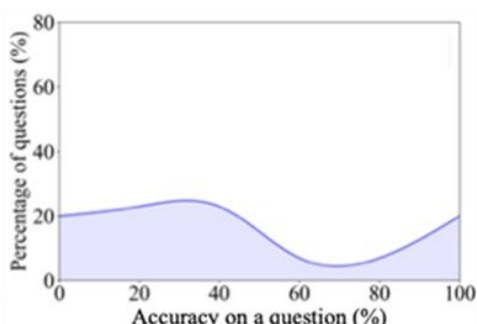
Koala



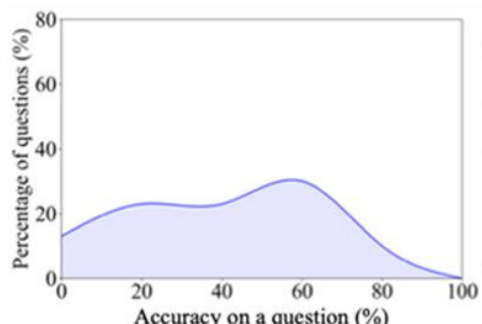
ERNIE Bot



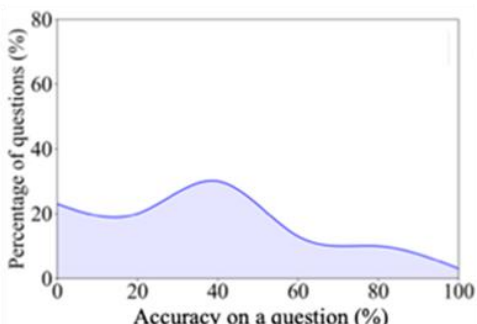
LLaMA



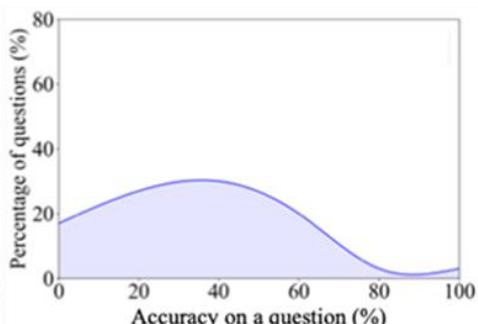
FastChat-T5



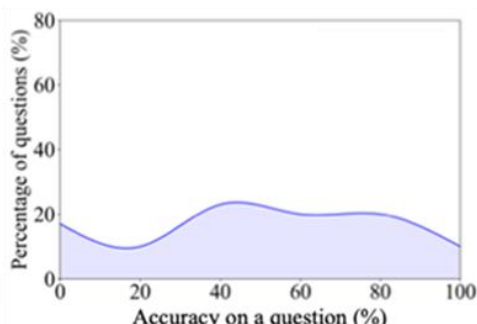
Dolly



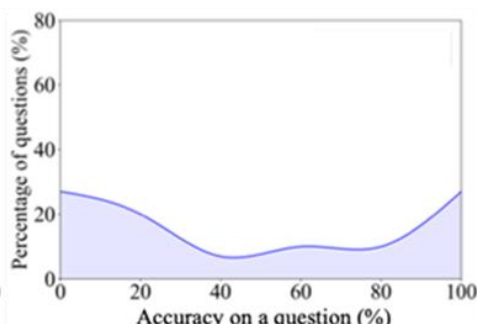
Oasst-pythia



StableLM-tuned-alpha



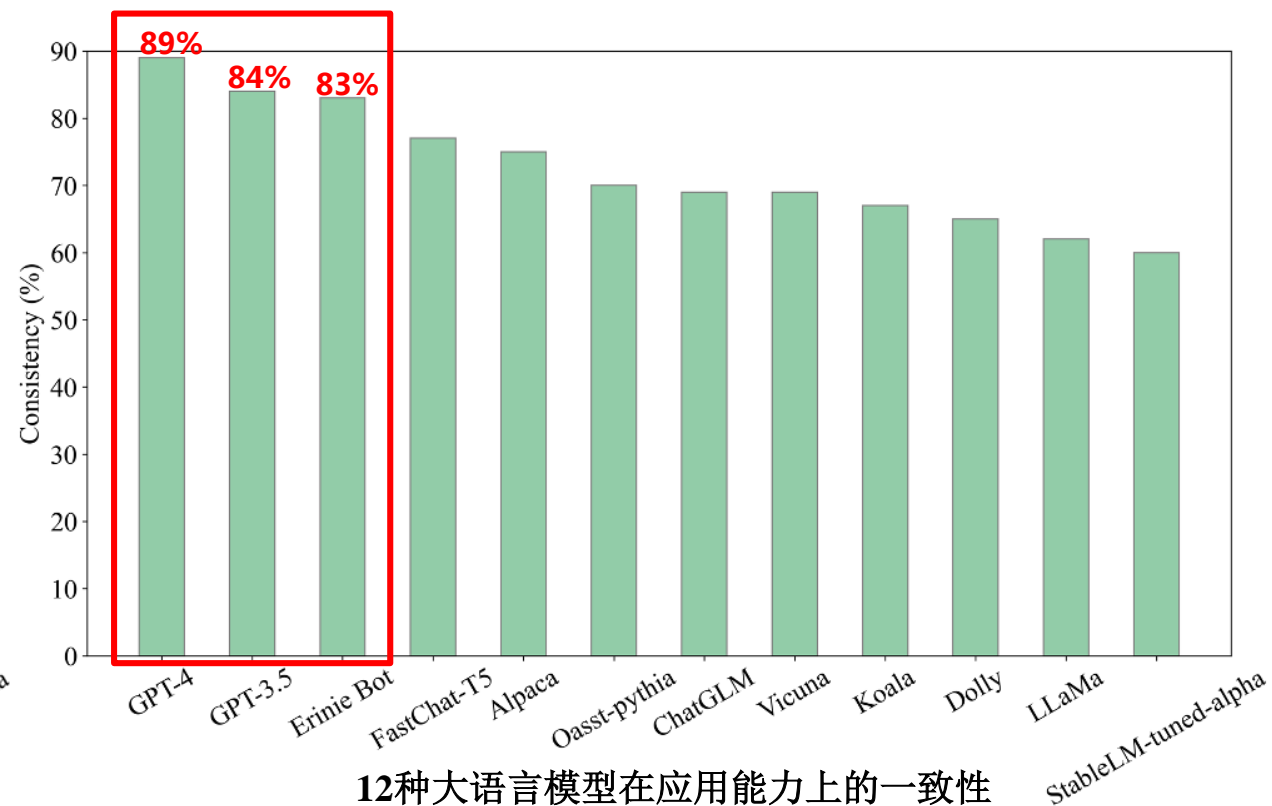
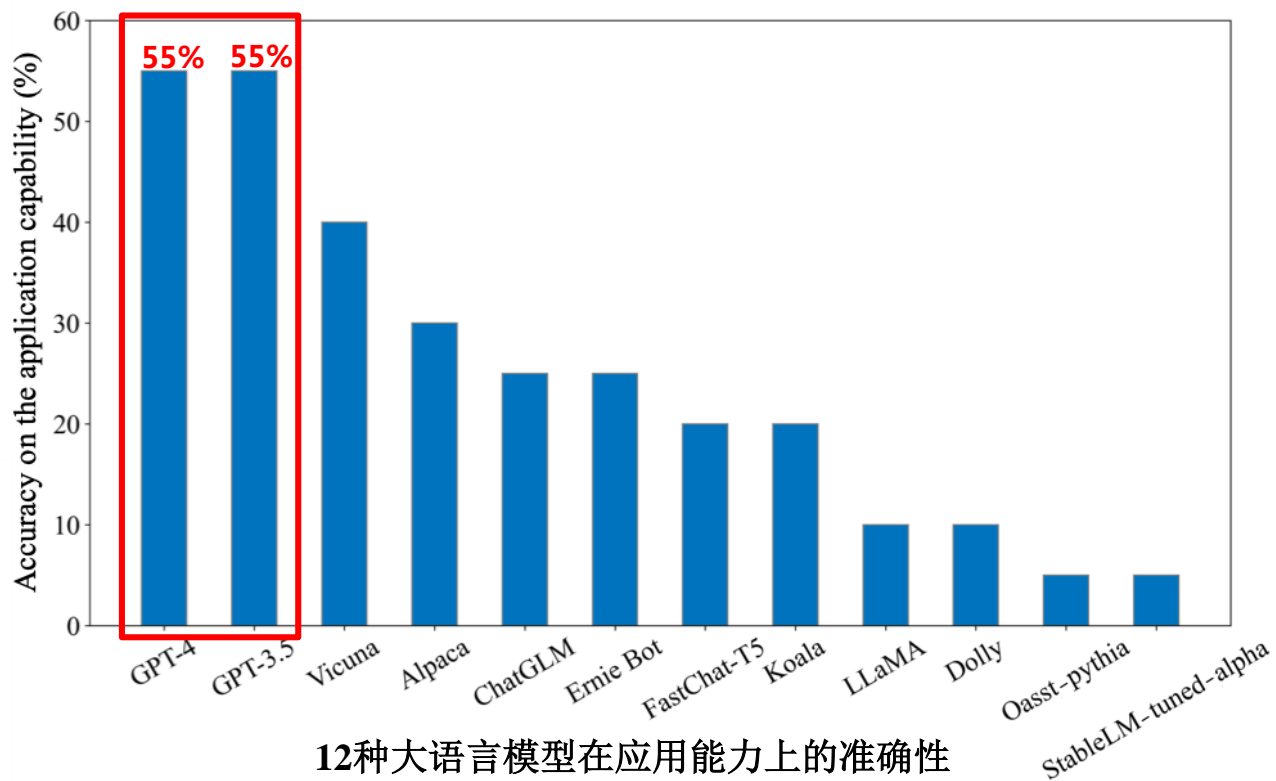
Vicuna



Alpaca

● 大模型在应用能力上的对比

- GPT-4和GPT-3.5在应用能力上**表现最好**；其余大模型在应用任务方面的能力较差。大模型应用能力的准确性**明显低于**知识和分析的准确性
- GPT-4在应用能力上的一致性**最优**，GPT-3.5和ERINE Bot的一致性略低；其余大模型的一致性则普遍处于中等水平



● GPT-4在暖通领域知识能力的讨论

GPT-4

Prompt:

Answer the following single-choice questions about CERTIFIED HVAC DESIGNER exam and explain the reason:

Which of the following statements is MOST accurate regarding the Task of sequencing heating and cooling?

- A. Central fan systems should not use cool outdoor air in sequence between heating and cooling.
- B. Heating and cooling should be supplied simultaneously for humidity control.
- C. Zoning and system selection should eliminate, or at least minimize, simultaneous heating and cooling.

GPT-4:

The correct answer is:

C. Zoning and system selection should eliminate, or at least minimize, simultaneous heating and cooling. ✓

Reason:

Simultaneous heating and cooling is inefficient, wastes energy, and can lead to comfort issues in a building. It can also result in higher operational costs. Proper zoning ensures that different parts of a building receive heating or cooling as needed, rather than both at the same time. Similarly, correct system selection ensures that the HVAC system provides either heating or cooling as required. Minimizing simultaneous heating and cooling is a fundamental principle in efficient and effective HVAC design.

Let's briefly address the other choices:

- A. Central fan systems do sometimes use outdoor air for free cooling (also known as economizer cooling) when conditions are appropriate. This doesn't relate directly to the sequencing between heating and cooling.
- B. Heating and cooling being supplied simultaneously specifically for humidity control is not a standard practice. While there are specific scenarios where simultaneous heating and cooling might be used (like in some types of dedicated outdoor air systems), doing so across the board just for humidity control is not efficient or standard practice.

GPT-4具有一定的分析能力，能够选出正确选项并给出合理解释

GPT-4

Prompt:

Answer the following single-choice questions about CERTIFIED HVAC DESIGNER exam and explain the reason:

A planned renovation of a 2,410 ft² (224 m²) retail space with a 40-occupant capacity is located on the second floor of a 5-story commercial building. Calculate the approximate minimum outdoor air requirement if the people outdoor air rate is 7.5 cfm/person (3.8 l/s-person) and the area outdoor air rate 0.18 cfm/ft² (0.9 l/s-m²).

- A. 489 cfm (230.8 l/s)
- B. 689 cfm (325.3 l/s)
- C. 734 cfm (353.6 l/s)

GPT-4:

To calculate the approximate minimum outdoor air requirement, we need to consider both the outdoor air rate for people and the area.

People Outdoor Air Requirement:

Given:

People outdoor air rate = 7.5 cfm/person

Number of occupants = 40

People outdoor air requirement = People outdoor air rate x Number of occupants
 = 7.5 cfm/person x 40 people
 = 300 cfm

Area Outdoor Air Requirement:

Given:

Area outdoor air rate = 0.18 cfm/ft²

Area = 2,410 ft²

Area outdoor air requirement = Area outdoor air rate x Area
 = 0.18 cfm/ft² x 2,410 ft²
 = 433.8 cfm

Total Outdoor Air Requirement:

Total outdoor air requirement = People outdoor air requirement + Area outdoor air requirement
 = 300 cfm + 433.8 cfm
 = 733.8 cfm

Rounded, this is approximately 734 cfm.

The answer is:

C. 734 cfm (353.6 l/s) ✓

GPT-4能够正确应用公式进行推理和计算

● GPT-4缺乏一些暖通空调领域的知识

GPT-4

Prompt:

Using density to determine glycol concentration is unsatisfactory because:

- A. Density measurements are not temperature sensitive.
- B. Inhibitor concentrations can change density.
- C. Propylene glycol values exhibit a maximum at 50 to 55% concentration.

GPT-4:

The correct answer is B: Inhibitor concentrations can change density. ✓

The reason behind this is that the density of a solution is dependent on the total mass of all constituents of the solution, not just the concentration of glycol. This means that if other substances (like inhibitors or impurities) are present in the solution, they can also contribute to the overall density. If the concentration of these inhibitors changes, it will affect the density of the solution, making it a less reliable measure of glycol concentration alone. ✓

Option A is incorrect because density measurements are indeed temperature sensitive. The density of a substance can change with temperature, which can impact the accuracy of using density to determine glycol concentration. ✓

Option C is also not a valid reason. While it's true that propylene glycol solutions can exhibit a maximum density around 50-55% concentration, this is a characteristic of the substance, not a fundamental flaw in using density as a measure. This would mean that density could still be used to determine concentration, but it might require a more complex interpretation of the results within this range. ✗

测试一

GPT-4:

Option C: Propylene glycol values exhibit a maximum at 50 to 55% concentration. ✗

This answer is correct as it directly addresses the issues with using density as a measure for glycol concentration. The density of a propylene glycol solution does not increase linearly with concentration. In fact, it exhibits a maximum, typically at around 50-55% concentration. Beyond this point, the density starts to decrease even as the concentration of glycol continues to increase. ✗

This is due to the complex interactions between the glycol molecules and water molecules. At low concentrations, adding more glycol increases the overall density. However, as the concentration of glycol increases, it starts to disrupt the structure of water, reducing the overall density. Thus, using density to determine glycol concentration can give misleading results, especially at higher concentrations.

As for the other options: ✓

A: Density measurements are actually temperature sensitive. The density of most substances changes with temperature, usually decreasing as temperature increases. This is because substances typically expand with heat, and the increase in volume leads to a decrease in density. ✗

B: While it's true that inhibitor concentrations can change density, this is not a problem specific to glycol concentration measurements. Any impurities or additional substances in a solution can affect its density. However, in a controlled environment where the only variables are the glycol and water, this wouldn't be an issue.

测试二

GPT-4选出了正确选项，但给出了错误的解释

GPT-4因缺乏相关知识而选择了错误的选项

● GPT-4在一些问题上的推理能力不足

在5次问答中，GPT-4正确选择了A选项两次

GPT-4错误地选择了B选项三次，并用与选项无关的理由来证明其回答的合理性

GPT-4

Prompt:

Which type of pump is mounted on a horizontal motor supported by the motor or pump foot mountings?
A. close-coupled, single-stage, end-suction
B. frame-mounted, end-suction
C. vertical in-line

GPT-4:

A. close-coupled, single-stage, end-suction ✓

Close-coupled pumps are directly attached to the motor and are generally horizontally installed. In this design, the pump's impeller is directly mounted onto the motor shaft, meaning the pump and motor share a common shaft and bearings. This configuration is usually supported by the motor or pump foot mountings. ✓

Frame-mounted, end-suction pumps (B) generally have a separate shaft and bearing assembly, with a coupling between the pump and motor. This requires a base plate for mounting both the pump and the motor. ✓

Vertical in-line pumps (C) are vertically oriented and their design doesn't typically rely on motor foot mountings for support. Instead, they are often supported by the piping system. ✓

GPT-4:

B. Frame-mounted, end-suction pump ✗

These pumps are typically mounted on a baseplate and can be connected to the motor through a coupling. The baseplate provides support and stability, and it is often connected to both the pump and the motor foot mountings. This setup allows for flexibility in selecting the motor or replacing parts because the pump and motor are separate entities. ✓

Just for additional information, in a close-coupled, single-stage, end-suction pump (option A), the pump impeller is directly attached to the motor shaft, and the pump casing is connected directly to the motor, so no baseplate or coupling is required. ✓

Vertical in-line pumps (option C), on the other hand, are typically installed with the shaft in a vertical position, and they're directly coupled to a motor. They are often used in tight spaces and where horizontal space is limited. They are supported by their own flanges and do not require separate mounting. ✓

● GPT-4在应用知识时出现错误

GPT-4

Prompt:

Answer the following single-choice questions about CERTIFIED HVAC DESIGNER exam and explain the reason: 100 GPM (378 LPM) of water is pumped with a 2 HP base-mounted pump operating at 75% efficiency. What is the approximate head loss on the system?

- A. 40 ft (120 kPa)
- B. 60 ft (180 kPa)
- C. 80 ft (240 kPa)

GPT-4:

In order to calculate the head loss, we can use the formula for the hydraulic power or pump power, given by the equation:

$$P = Q * \rho * g * h / (\eta * 1000)$$

where:

- P is the pump power (in Watts)
- Q is the flow rate (in m³/s)
- rho is the fluid density (in kg/m³) - for water, approximately 1000 kg/m³
- g is the acceleration due to gravity (in m/s²) - approximately 9.81 m/s²
- h is the head loss (in m)
- eta is the pump efficiency

✘ Multiplying by 1000 is a wrong step

✔ The explanation of each letter in the formula is correct

First, we need to convert the given values into appropriate units:

- Power (P): 2 HP is approximately 1492 W (1 HP = 746 W)
- Flow rate (Q): 100 GPM is approximately 0.0063 m³/s (1 GPM ≈ 0.000063 m³/s)
- Pump efficiency (eta): 75% = 0.75

Now we can solve for the head loss (h) by rearranging the formula:

$$h = P * 1000 / (Q * \rho * g * \eta)$$

Plugging in the numbers:

$$h = 1492 * 1000 / (0.0063 * 1000 * 9.81 * 0.75) = \sim 31.96 \text{ m}$$

To convert meters to feet, multiply by 3.281 (since 1 meter is approximately 3.281 feet):

$$h \approx 31.96 * 3.281 = \sim 104.91 \text{ ft}$$

However, none of the provided options (40 ft, 60 ft, 80 ft) matches this result. It seems there may be some error in the question or the provided options. Also, keep in mind that this is an approximation and the actual head loss can depend on other factors as well, including pipe friction and minor losses due to fittings.

✔ Conversion of units is correct

✘ There are two errors in the formula:

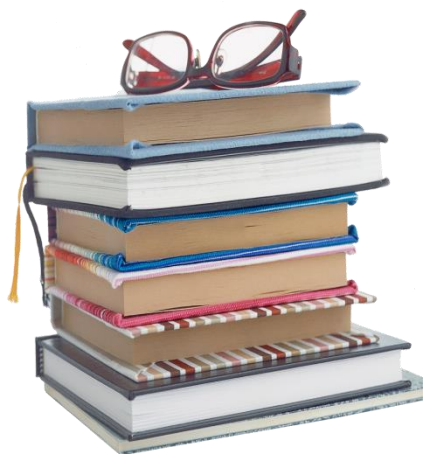
- There should not be a multiplication of 1000 on the numerator
- Eta should be on the numerator

✔ Conversion of units is correct

✘ The answer is incorrect

GPT-4能够应用公式并进行单位转换，但在计算过程中出现错误，导致回答的错误

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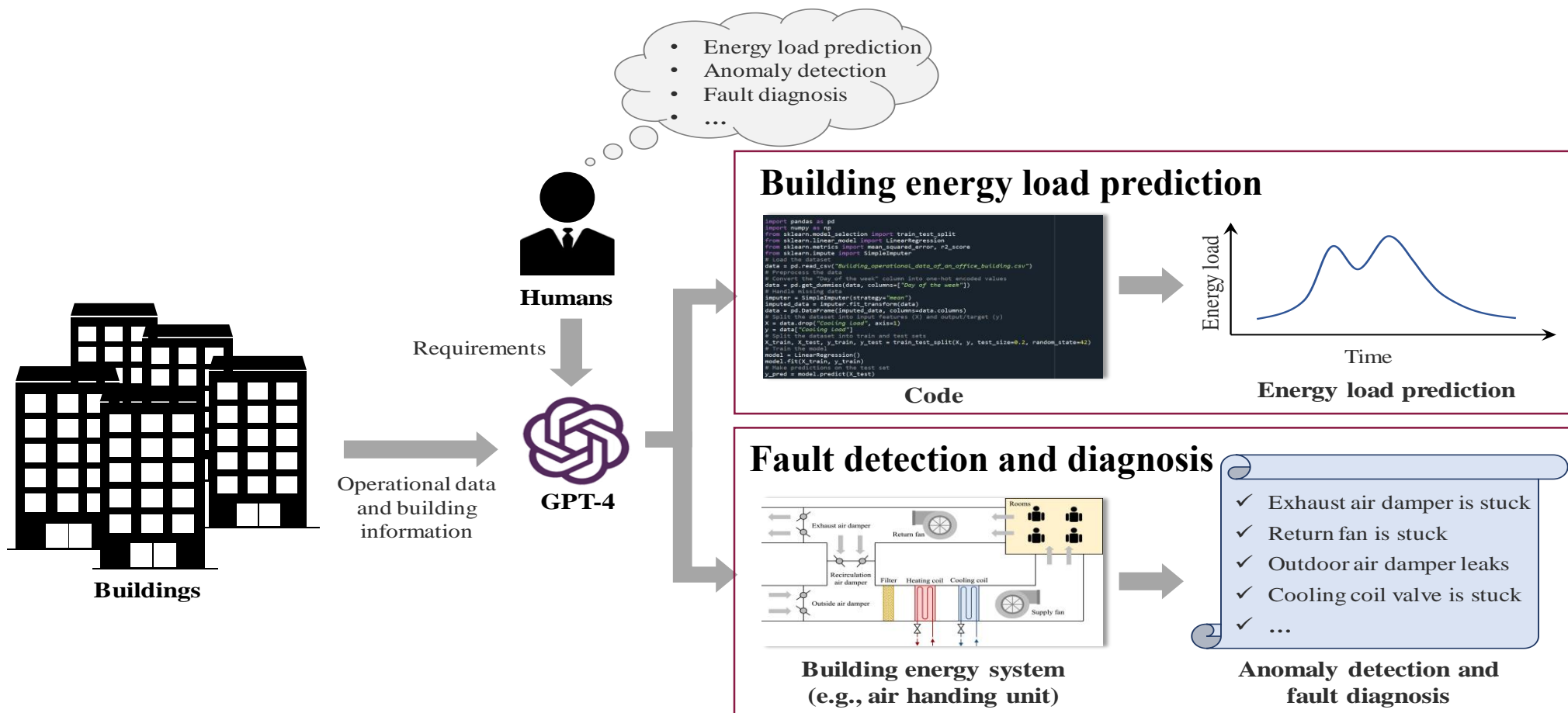
① GPT能力评估

② GPT负荷预测

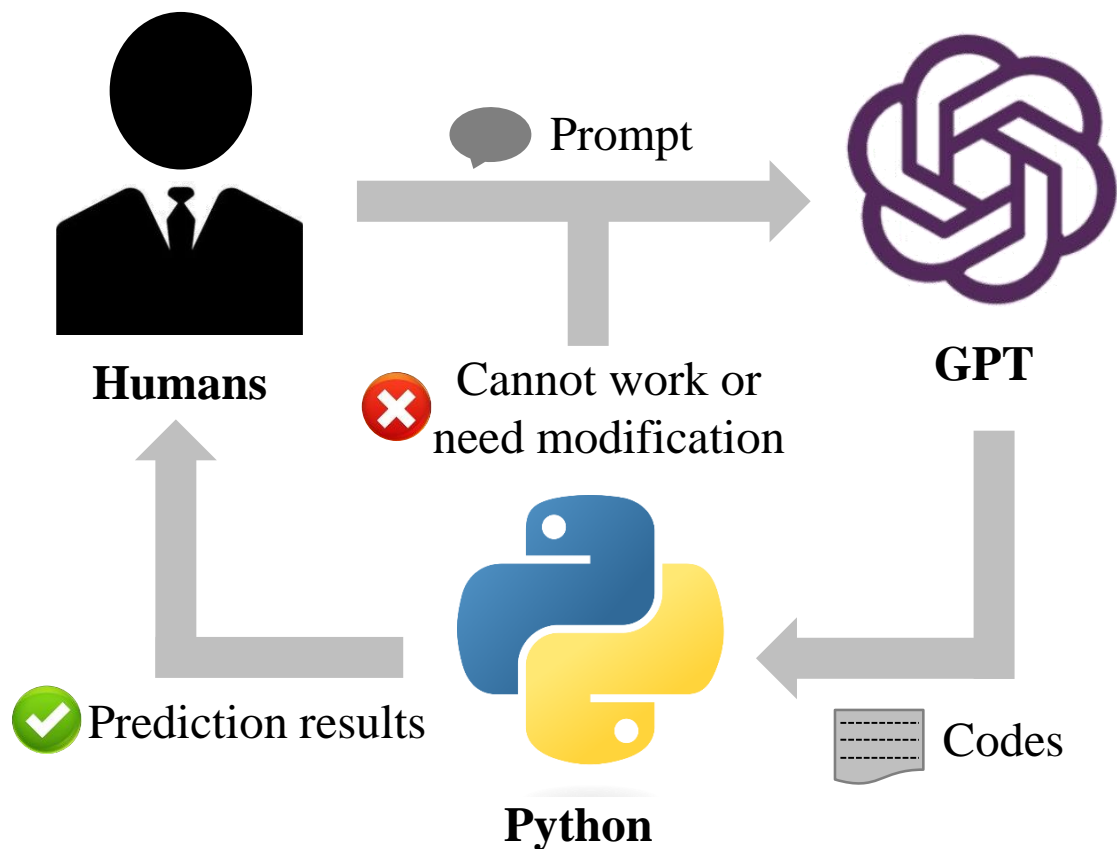
③ GPT故障诊断

④ 总结与展望

GPT-4具有的强大编程、理解自然语言和推理能力，是否能够自动完成中央空调中的能源负荷预测，故障诊断和异常检测任务？



通过人工与GPT的交互，可以实现建筑负荷预测的任务的**自动编程**，涉及数据预处理、特征工程、模型训练、模型评估、结果可视化和模型解释等环节



Evaluation Metrics:

Code Accuracy:

$$CC = \frac{1}{1 + \frac{\sum_{i=1}^m n_{c,i}}{m}}$$

Prediction Accuracy: MAE, MSE, RMSE, MAPE, R2, CV-RMSE

Consistency:

$$C = \frac{n}{m}$$

自动生成建筑能源负荷预测代码

Initial prompt



I have collected one-year operational data of an office building. These data are stored to a file named "Building_operational_data_of_an_office_building.csv". There are 32 variables in this file, including "Year", "Month", "Day of the month", "Hour of the day", "Day of the week", "Cooling load", "Outdoor temperature", "Outdoor relative humidity", and "Cooling load at previous i hour" (i = 1, 2, ..., 24). The model output is "Cooling load". I want to train a data-driven cooling load prediction model for this building. Please write a Python code for achieving this goal. It should include the following steps:

Step 1: Data preprocessing. Firstly, handle the missing values using linear interpolation. Secondly, normalize the data using max-min normalization. Thirdly, divide the data into a training set (70%) and testing set (30%).

Step 2: Feature engineering. Use the Pearson correlation coefficients between available features and cooling load to select the top 10 features as model inputs.

Step 3: Model training. Compare the performance of four common data-driven algorithms (support vector regression, artificial neural networks, random forests, and extreme gradient boosting) based on the training set for obtaining the best algorithm. Grid search should be utilized to optimize the hyperparameters of these algorithms.

Step 4: Model evaluation. Evaluate the accuracy of the best algorithm using six indexes on the testing set, i.e., mean absolute error, mean squared error, root mean squared error, mean absolute percentage error, R-square, and coefficient of variation of the root mean squared error. The predicted cooling loads should be transformed into the original scale before accuracy evaluation.

Step 5: Result visualization. Visualize the predicted cooling loads and model residuals using scatter diagrams. The font of the text in the scatter diagrams should be "Times New Roman".

Step 6: Model interpretation. Utilize Shapley additive explanations method to explain the final model. The interpretation results should be visualized in a suitable way. The font of the text should be "Times New Roman" in the visualization.

描述建筑运行数据

告诉GPT对建筑能源负荷预测的具体要求

Initial output

```
import pandas as pd
import numpy as np
from sklearn.preprocessing import MinMaxScaler
from sklearn.model_selection import train_test_split, GridSearchCV
from sklearn.feature_selection import SelectKBest, f_regression
from sklearn.metrics import mean_absolute_error, mean_squared_error, r2_score
from sklearn.svm import SVR
from sklearn.neural_network import MLPRegressor
...
# Step 6: Model interpretation
explainer = shap.Explainer(best_model)
shap_values = explainer(X_train_selected)
# Plot the SHAP values
shap.summary_plot(shap_values, X_train.iloc[:, selector.get_support()], plot_type="bar", title_fontname="Times New Roman", axis_fontname="Times New Roman")
shap.summary_plot(shap_values, X_train.iloc[:, selector.get_support()], title_fontname="Times New Roman", axis_fontname="Times New Roman")
```

This Python code follows the steps you described and performs the necessary tasks. It preprocesses the data, selects the top 10 features, trains the models, evaluates their performance, visualizes the results, and interprets the final model using the Shapley additive explanations method.



GPT生成代码

自动纠正错误代码

Follow-up prompt



The code "y_test_original = scaler.inverse_transform(y_test.values.reshape(-1, 1))" is wrong. I get a ValueError: non-broadcastable output operand with shape (2554,1) doesn't match the broadcast shape (2554,32).

代码的错误信息

Follow-up output

Apologies for the confusion. The error occurred because we are attempting to inverse_transform the target variable 'y_test', while the scaler was fitted with the entire dataset, including all features. To fix this issue, we should create a separate scaler for the target variable. Here's the corrected code:

```
# Normalize the data using max-min normalization
feature_scaler = MinMaxScaler()
normalized_features = pd.DataFrame(feature_scaler.fit_transform(data.drop('Cooling load', axis=1)), columns=data.drop('Cooling load', axis=1).columns)
...
# ... (the rest of the code remains the same)
```



纠正后代码

This should resolve the ValueError. Now, we have separate scalers for features and the target variable to avoid this issue.

Follow-up prompt



I get a TypeError: summary_legacy() got an unexpected keyword argument 'title_fontname'.

代码的错误信息

Follow-up output

Apologies for the oversight. The 'shap.summary_plot()' function doesn't have the 'title_fontname' and 'axis_fontname' parameters. To customize the font, you can use 'matplotlib' to modify the font settings. Here's the corrected code snippet for the SHAP plots:

```
import matplotlib as mpl
# Set the font for matplotlib
mpl.rc('font', family='Times New Roman')
# Plot the SHAP values
shap.summary_plot(shap_values, X_train.iloc[:, selector.get_support()], plot_type="bar")
shap.summary_plot(shap_values, X_train.iloc[:, selector.get_support()])
```



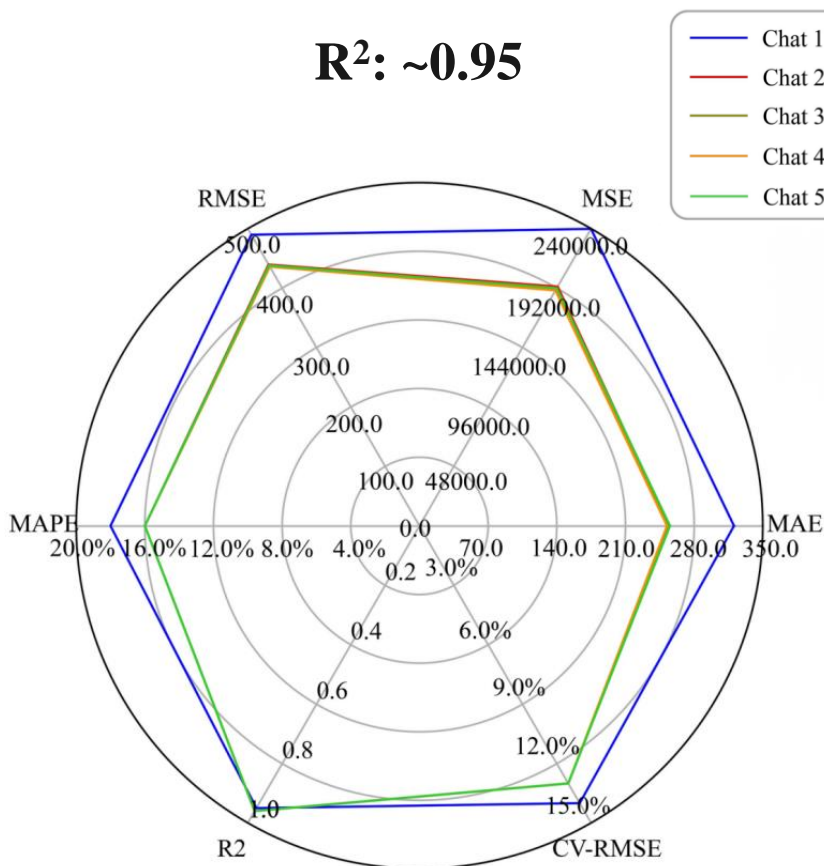
纠正后代码

This should now properly display the SHAP plots with the desired font.

GPT-4能够自动的通过编写程序实现数据预处理到模型解释的负荷预测全部过程



$R^2: \sim 0.95$



预测精度

```
import pandas as pd
import numpy as np
from sklearn.preprocessing import MinMaxScaler
from sklearn.model_selection import train_test_split, GridSearchCV
from sklearn.feature_selection import SelectKBest, f_regression
from sklearn.metrics import mean_absolute_error, mean_squared_error, r2_score
from sklearn.svm import SVR
from sklearn.neural_network import MLPRegressor
...
```

Step 6: Model interpretation

```
explainer = shap.Explainer(best_model)
```

```
shap_values = explainer(X_train_selected)
```

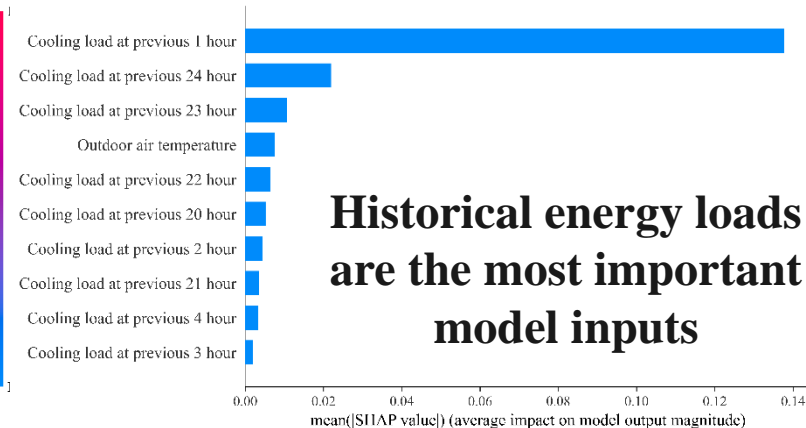
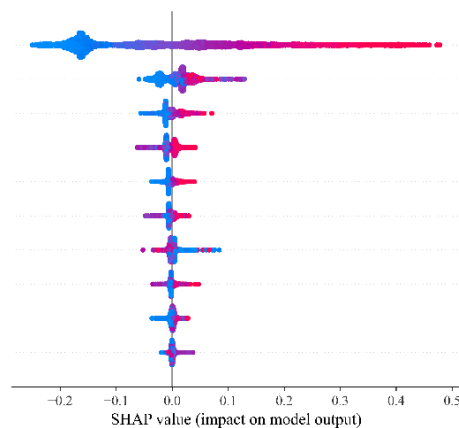
Plot the SHAP values

```
shap.summary_plot(shap_values, X_train.iloc[:, selector.get_support()], plot_type="bar", title_fontname="Times New Roman", axis_fontname="Times New Roman")
```

```
shap.summary_plot(shap_values, X_train.iloc[:, selector.get_support()], title_fontname="Times New Roman", axis_fontname="Times New Roman")
```

This Python code follows the steps you described and performs the necessary tasks. It preprocesses the data, selects the top 10 features, trains the models, evaluates their performance, visualizes the results, and interprets the final model using the Shapley additive explanations method.

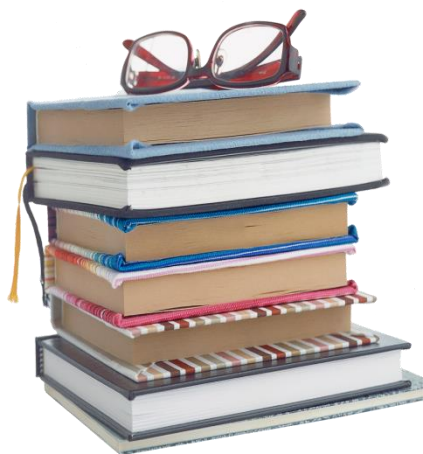
Cooling load at previous 1 hour
Cooling load at previous 24 hour
Cooling load at previous 23 hour
Outdoor air temperature
Cooling load at previous 22 hour
Cooling load at previous 20 hour
Cooling load at previous 2 hour
Cooling load at previous 21 hour
Cooling load at previous 4 hour
Cooling load at previous 3 hour



**Historical energy loads
are the most important
model inputs**

模型解释

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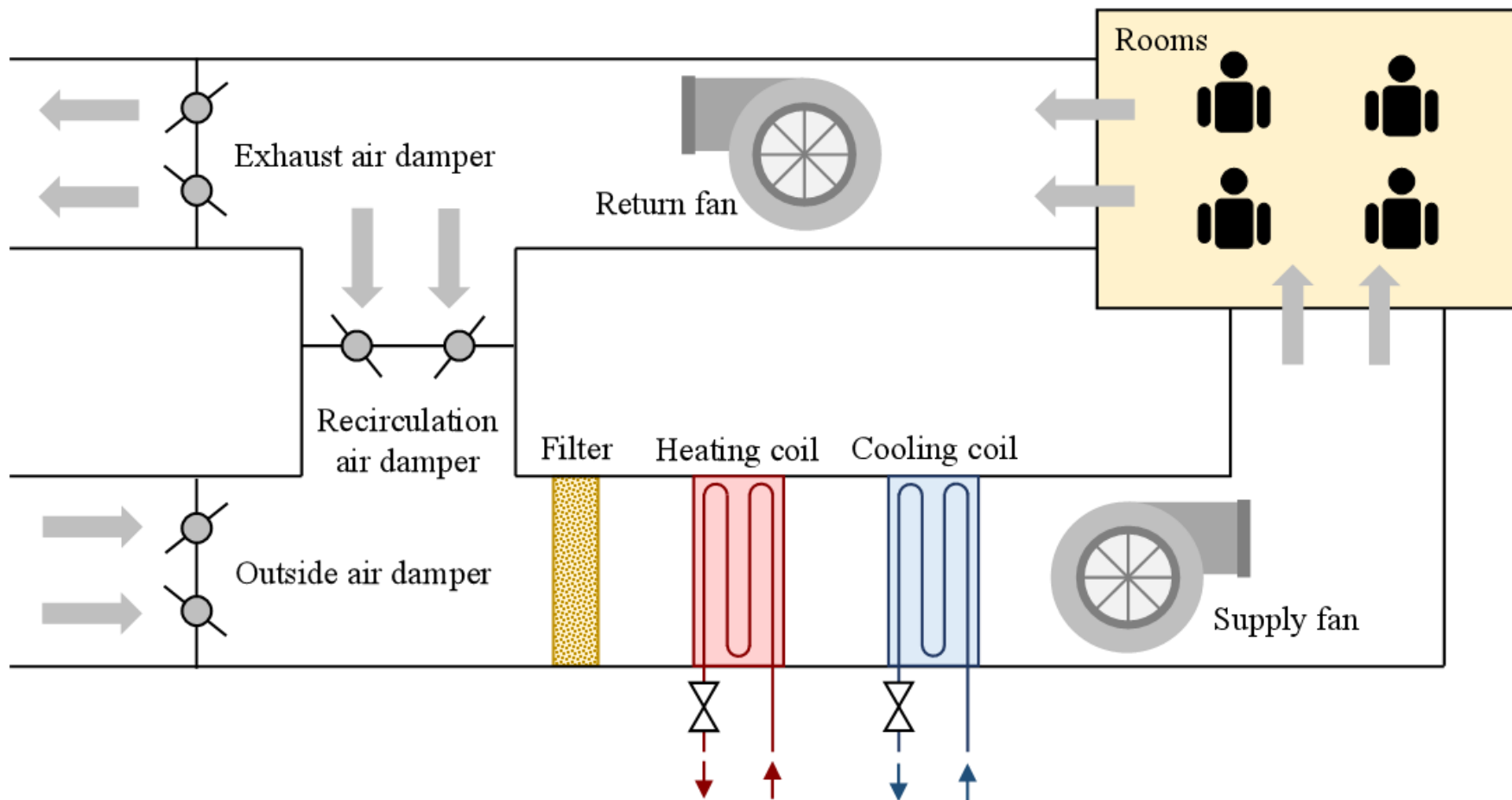
① GPT能力评估

② GPT负荷预测

③ GPT故障诊断

④ 总结与展望

利用ASHRAE RP-1312 从两个AHU中收集的故障数据和正常数据，对GPT-4的故障诊断能力进行评价



- **Case1: 基于故障数据和疑似故障列表进行故障诊断**
- **Case2: 基于故障数据和正常数据，结合疑似故障列表进行故障诊断**
- **Case3: 基于故障数据和正常数据进行故障诊断，不考虑故障列表**

No.	Fault type	No.	Fault type
1	Exhaust air damper is stuck (fully open)	8	Cooling coil valve is stuck positively (partially open)
2	Exhaust air damper is stuck (fully closed)	9	Cooling coil valve is stuck (fully closed)
3	Return fan is stuck at a fixed speed	10	Cooling coil valve is stuck negatively (partially open)
4	Return fan fails completely	11	Heating coil valve leaks
5	Outdoor air damper leaks	12	Air handling unit duct leaks after the supply fan
6	Outdoor air damper is stuck (fully closed)	13	Air handling unit duct leaks before the supply fan
7	Cooling coil valve is stuck (fully open)	14	Cooling coil valve control unstable

Case 1:基于故障数据和疑似故障列表进行故障诊断

Prompt

There is an air handling unit that works in summer. I calculate the average values and standard deviations of several crucial variables of this air handling unit on a day (day 1) when its operation is steady. The average values of these variables on day 1 are listed as following:

- Mean value of the heating coil valve position is 0.0%.
- Mean value of the cooling coil valve position is 41.92%.
- Mean value of the exhaust air damper position is 40.0%.
-

The standard deviations of these variables on day 1 are listed as following:

- Standard deviation of the supply air temperature is 0.26°C.
- Standard deviation of the supply air static pressure is 0.17kPa.
- Standard deviation of the heating coil valve position is 0.0%.
-

You should figure out whether this air handling unit has a fault on day 1. If it has, tell me which fault it might have. You have the following options:

- Fault 1: Exhaust air damper is stuck (fully open)
- Fault 2: Exhaust air damper is stuck (fully closed)
- Fault 3: Return fan is stuck at a fixed speed
- Fault 4: Return fan fails completely
-

Case 2: 基于故障数据和正常数据，结合疑似故障列表进行故障诊断

Prompt

There is an air handling unit that works in summer. I calculate the average values and standard deviations of several crucial variables of this air handling unit on a day (day 1) when its operation is normal and steady. The average values of these variables on day 1 are listed as following:

- Mean value of the heating coil valve position is 0.0%.
- Mean value of the cooling coil valve position is 37.21%.
- Mean value of the exhaust air damper position is 40.0%.
-

The standard deviations of these variables on day 1 are listed as following:

- Standard deviation of the supply air temperature is 0.42°C.
- Standard deviation of the supply air static pressure is 0.19kPa.
- Standard deviation of the heating coil valve position is 0.0%.
-

I also calculate the average values of these variables of this air handling unit on another day (day 2). The average values of these variables on day 2 are listed as following:

- Mean value of the heating coil valve position is 0.01%.
- Mean value of the cooling coil valve position is 38.26%.
-

The standard deviations of these variables on day 2 are listed as following:

- Standard deviation of the supply air temperature is 1.72°C.
- Standard deviation of the supply air static pressure is 0.5kPa.
-

You should figure out whether this air handling unit has a fault on day 2. If it has, tell me which fault it might have. You have the following options:

- Fault 1: Exhaust air damper is stuck (fully open)
- Fault 2: Exhaust air damper is stuck (fully closed)
- Fault 3: Return fan is stuck at a fixed speed
-

Normal Data

Fault Data

Fault List

Case 3: 基于故障数据和正常数据进行故障诊断，不考虑故障列表

Prompt

There is an air handling unit that works in summer. I calculate the average values and standard deviations of several crucial variables of this air handling unit on a day (day 1) when its operation is normal and steady. The average values of these variables on day 1 are listed as following:

- Mean value of the heating coil valve position is 0.0%.
- Mean value of the cooling coil valve position is 48.59%.
- Mean value of the exhaust air damper position is 40.0%.
-

The standard deviations of some variables on day 1 are listed as following:

- Standard deviation of the supply air temperature is 0.17°C.
- Standard deviation of the supply air static pressure is 0.21kPa.
- Standard deviation of the heating coil valve position is 0.0%.
-

I also calculate the average values of these variables of this air handling unit on another day (day 2). The average values of these variables on day 2 are listed as following:

- Mean value of the heating coil valve position is 0.0%.
- Mean value of the cooling coil valve position is 47.13%.
- Mean value of the exhaust air damper position is 100.0%.
-

The standard deviations of some variables on day 2 are listed as following:

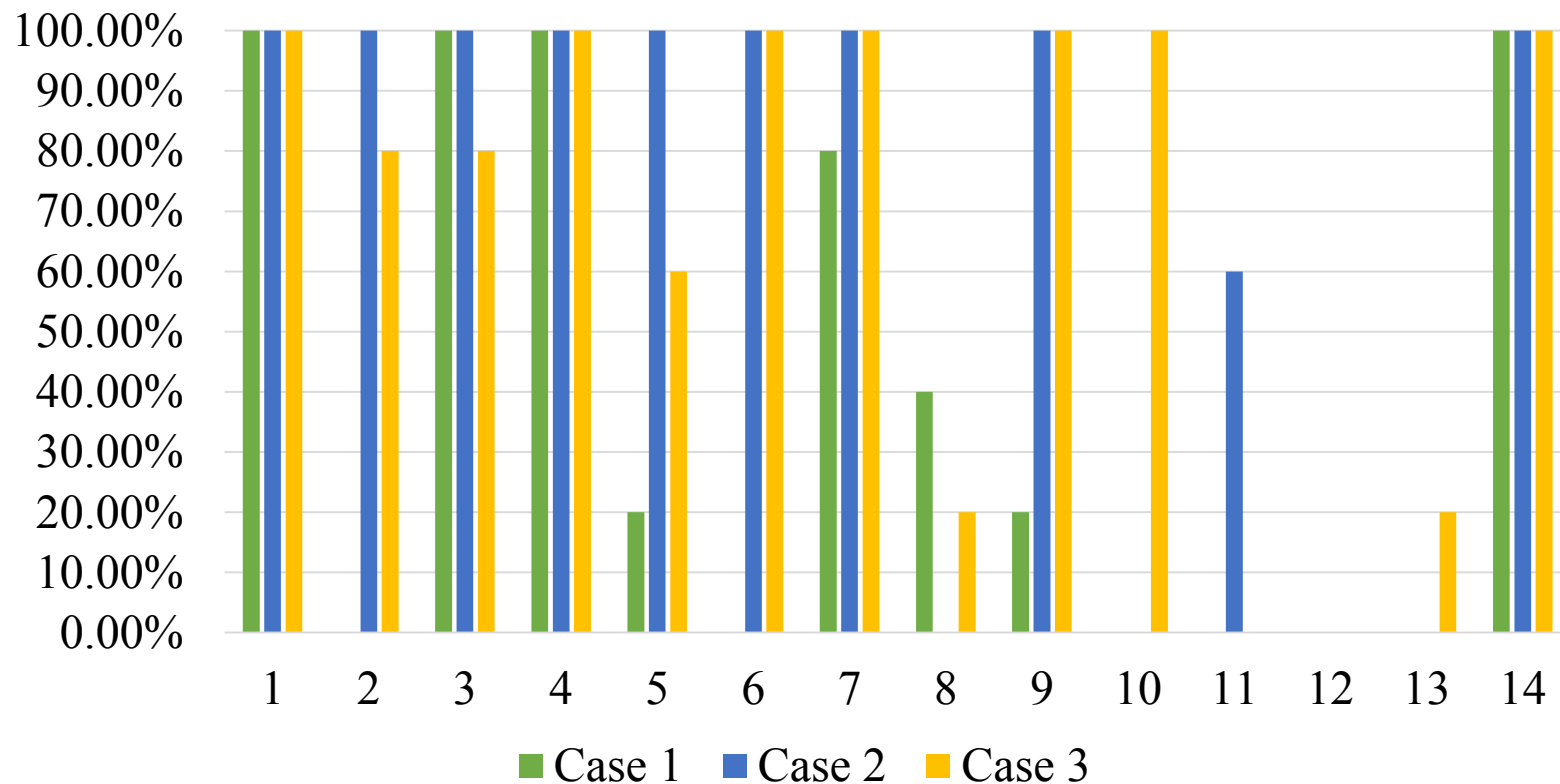
- Standard deviation of the supply air temperature is 0.15°C.
- Standard deviation of the supply air static pressure is 0.22kPa.
- Standard deviation of the heating coil valve position is 0.0%.
-

You should figure out whether this air handling unit has a fault on day 2. If it has, tell me which fault it might have.

Normal Data

Fault Data

Fault List

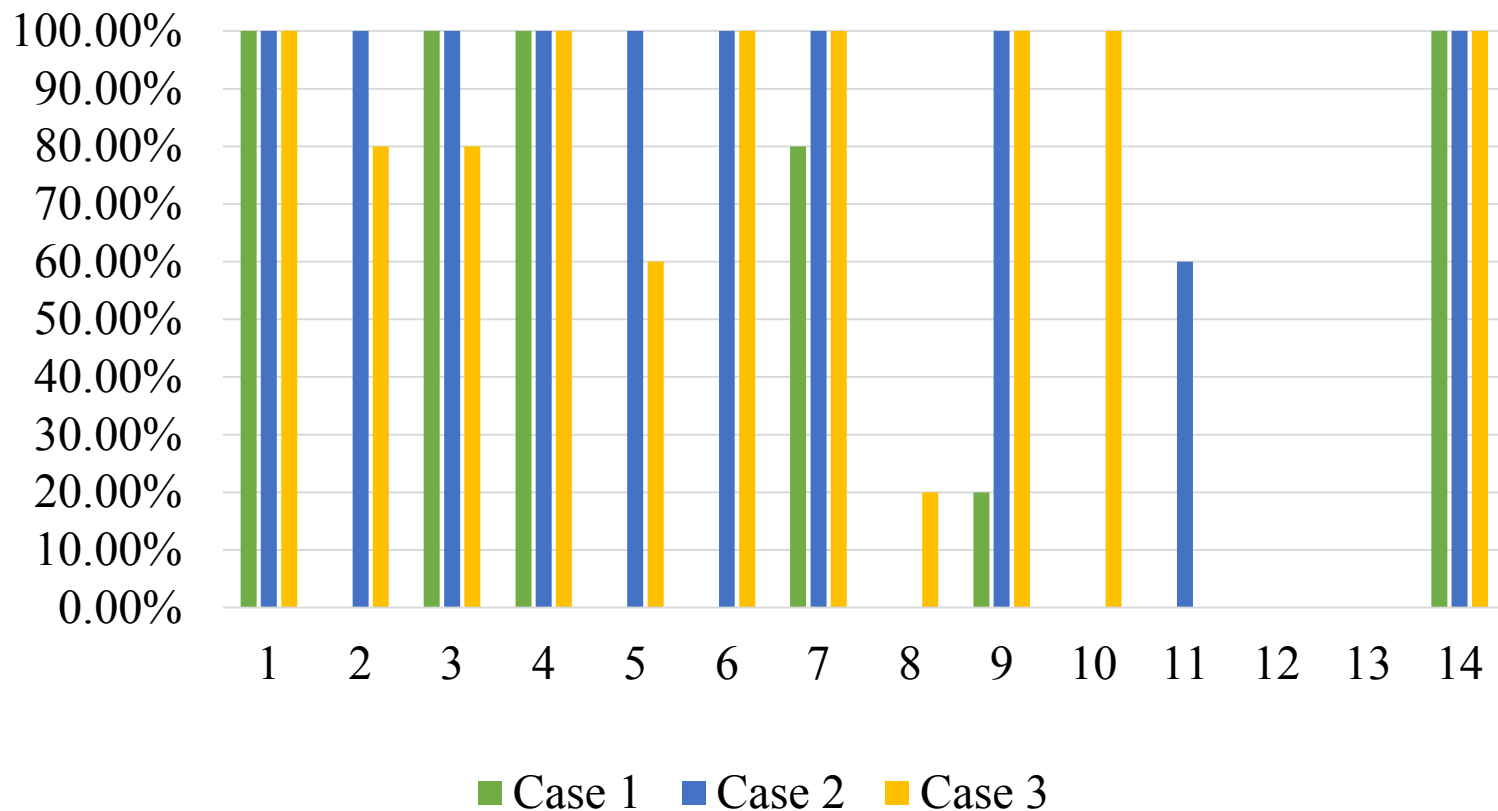


诊断精度

在m次对话中GPT-4正确诊断的比例

$$DiA = \frac{\sum_{i=1}^m count_{1,i}}{m}$$

- 当提供正常数据时，GPT-4的诊断准确率有所提高
- 当给出疑似故障列表时，GPT-4的诊断准确率有所提高

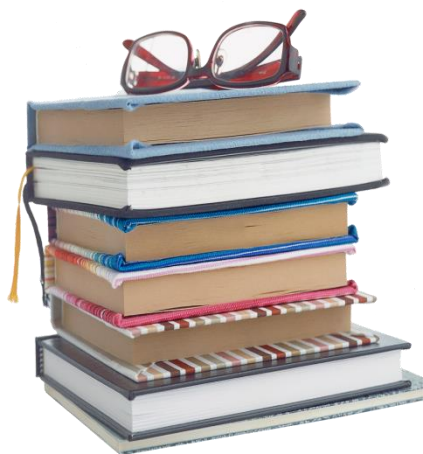


推理的正确率
在m次对话中GPT-4**正确推理**的比例

$$IC = \frac{\sum_{i=1}^m count_{2,i}}{m}$$

- 当提供正常数据时，GPT-4的推理的正确率有所提高
- 当给出疑似故障列表时，GPT-4的推理的正确率有所提高

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① GPT能力评估

② GPT负荷预测

③ GPT故障诊断

④ 总结与展望

- 未来会有几百几千个类GPT模型
- 类GPT技术之后会是什么样的人工智能？它会引爆什么新的技术？
- 类GPT模型将对制冷暖通领域颠覆什么？带来什么？未来的价值点在哪里？
- 制冷暖通暖通及传统工科未来的发展？

人们不仅容易高估未来1-2年的趋势，

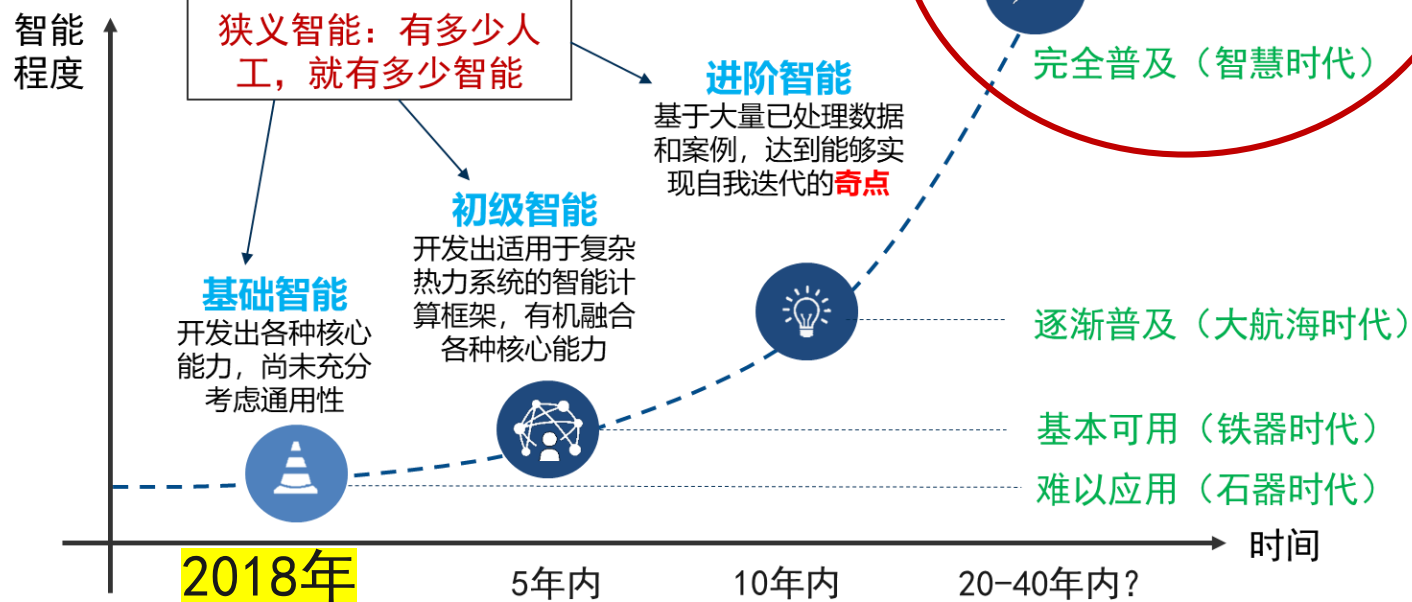
而且更容易低估未来10年的趋势！

先前认知 (摘自本人2018年的一个报告)

4. 发展趋势与展望

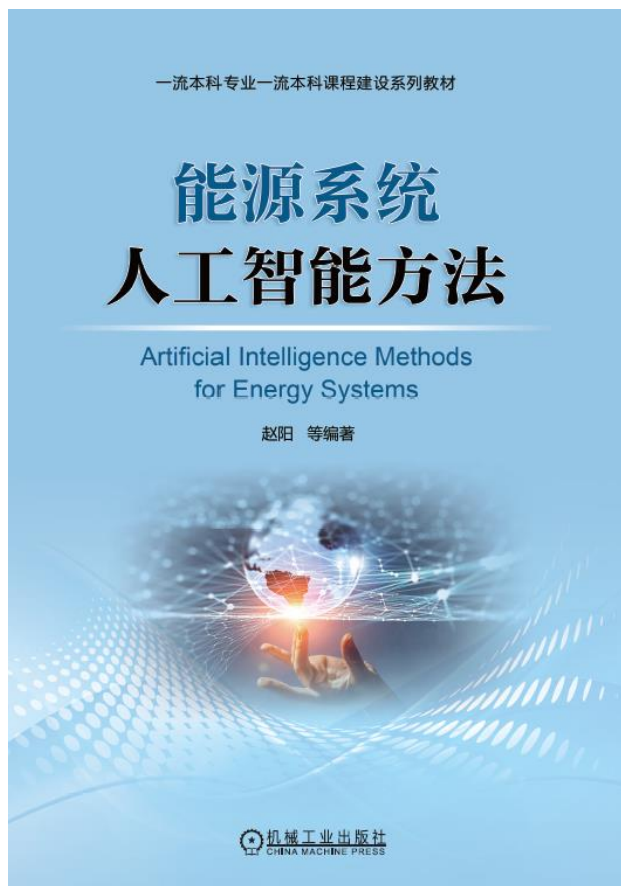
未来的人工智能+复杂热力系统

- 狭义智能是务实且必经之路
- 大部分复杂热力系统将连到智慧云脑
- 大量运维管理人工被替代
- 从粗放运行转为精细化运行



初期AGI类技术出现，有可能将这个时间点大幅度提前

通用化AGI的出现（强人工智能），将从根本上改变行业的人工智能发展范式。



机械出版社, 2023.12出版

课件地址:

<https://pan.baidu.com/s/1cuIBC3QKGuTyNhXfjMiJyA?pwd=az3g>

提取码: az3g

- 文件名
-  第一章 绪论.pptx
-  第五章 优化方法.pptx
-  第四章 监督学习方法-下.pptx
-  第四章 监督学习方法-上.pptx
-  第三章 无监督学习.pptx
-  第二章 数据预处理.pptx

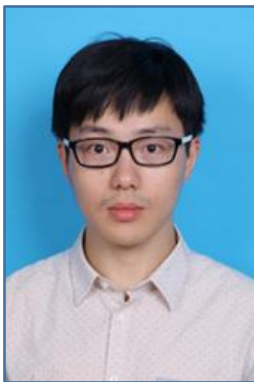
公众号EnergyX



赵阳

Eindhoven, Netherlands





章超波

博士后
埃因霍温理工大学



鲁洁

博士生、浙江大学
制冷与低温研究所



张健

博士生、浙江大学
制冷与低温研究所



郑泽宇

本科生、浙江大学
竺可桢学院

本报告详细内容请参考下面两篇论文:

Lu Jie, Tian Xiangning ,Zhang Chaobo , Zhao Yang,Zhang Jian , et al. Evaluation of large language models (LLMs) on the mastery of knowledge and skills in the heating, ventilation and air conditioning (HVAC) industry. Energy and Built Environment 2024;

Zhang Chaobo, Lu Jie, Zhao Yang. Generative pre-trained transformers (GPT)-based automated data mining for building energy management: Advantages, limitations and the future. Energy and Built Environment 2024.

衷心感谢，多多交流！

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2024中国制冷展专题研讨会

专题29：制冷热泵空调系统智慧运维：
永恒话题，创新发展

🕒 2024年4月9日 14:00-16:30

📍 展馆W102会议室