Herrick Laboratories PURDUE UNIVERSITY

2014 Purdue Conferences
Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

Simultaneous Control of Indoor Temperature and Humidity Using a VS DX A/C System

A PD Law based Fuzzy Logic Controller

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- Introduction
- Development of the controller
- The experimental setup and conditions
- The experimental results
- Conclusions

- The application of DX A/C system

Large scaled buildings: Chilled water based central air conditioner (A/C)

Small-to medium-scaled buildings: Direct Expansion (DX) A/C system

Advantages: compact, flexible, energy efficient, cost less.

- Conventional control strategy

ON / OFF control: leave the indoor air humidity uncontrolled

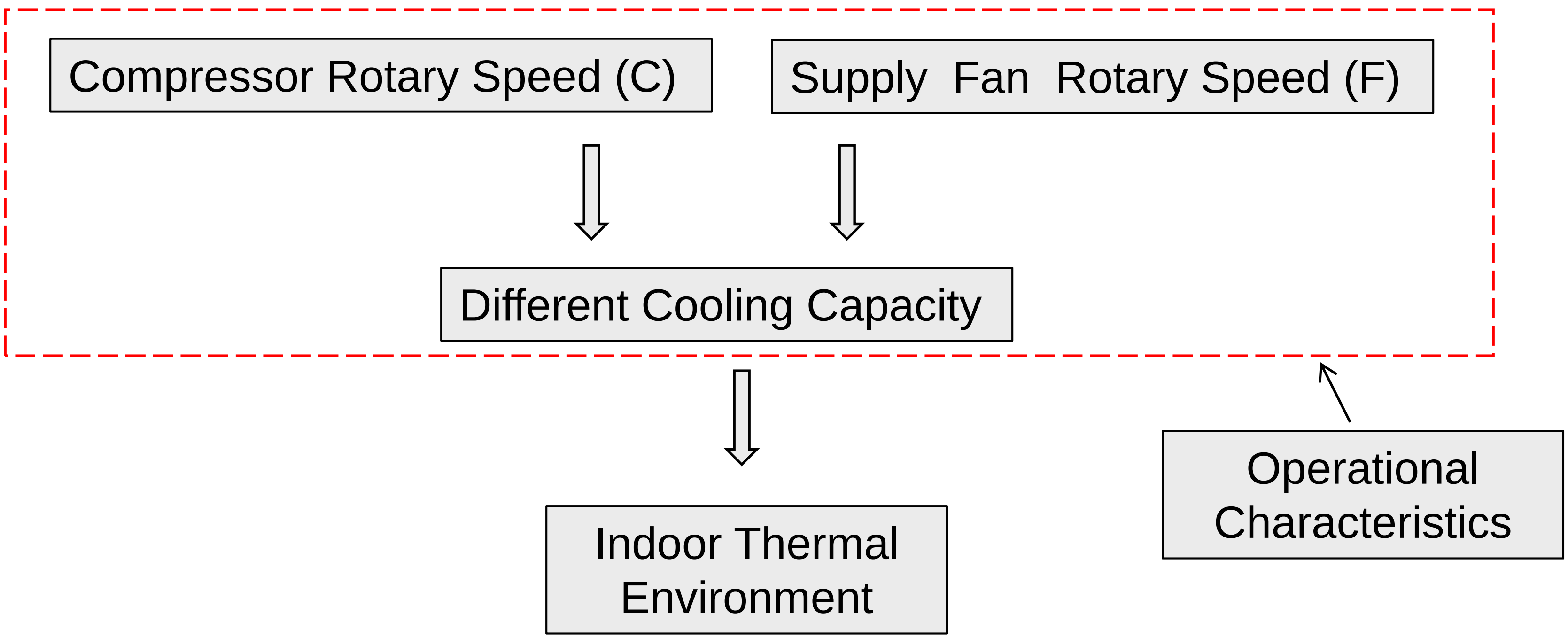
Simultaneous control of indoor temperature and humidity:

Total Cooling Capacity= Indoor cooling load & E SHR=A SHR

Introduction

- Variable Speed Driven

VSD ⟶ Continues speed variation for Fan & Compressor



Introduction

- Some novel control strategies

Physical model based controller:

DDC based Capacity controller; MIMO Controller

Empirical model based controller:

ANN based Online adaptive Controller

Simple PID controller:

Control algorithm: C ⟶ Indoor air temperature; F ⟶ Indoor air humidity

H-L Control:

Control algorithm: No OFF period for Compressor, but high and low rotary speed

Performance promised but complicated

↕ Conflict

Structure Simplified but without strict control of parameters

- Proposition

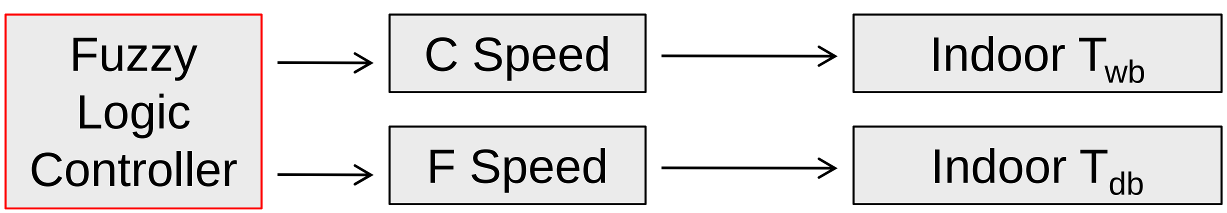
Certain logic : Using accurate mathematical and physical model

Fuzzy logic : Using common sense and experience of people

⇓

Effective means of capturing the approximate and inexact nature of the real world

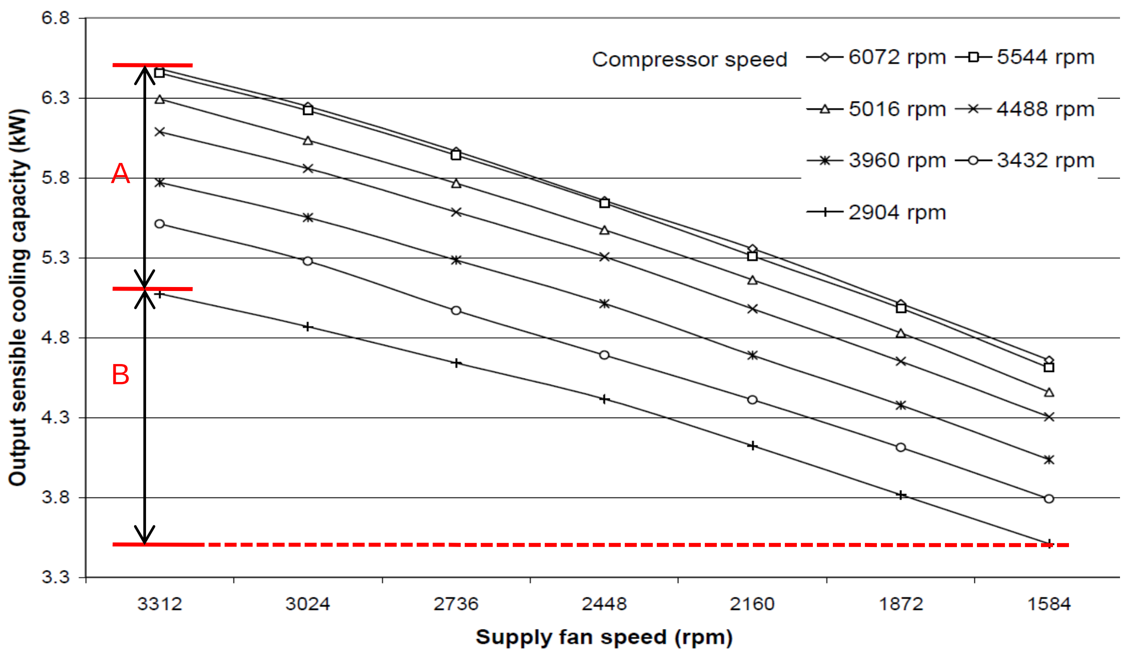
Proposed Control Strategy:



Development of the controller

- Proposed control principle

Operational characteristics:



Output sensible cooling capacity (Qs) at different speeds combination

A: Sensible cooling capacity change due to C speed variation

B: Sensible cooling capacity change due to F speed variation

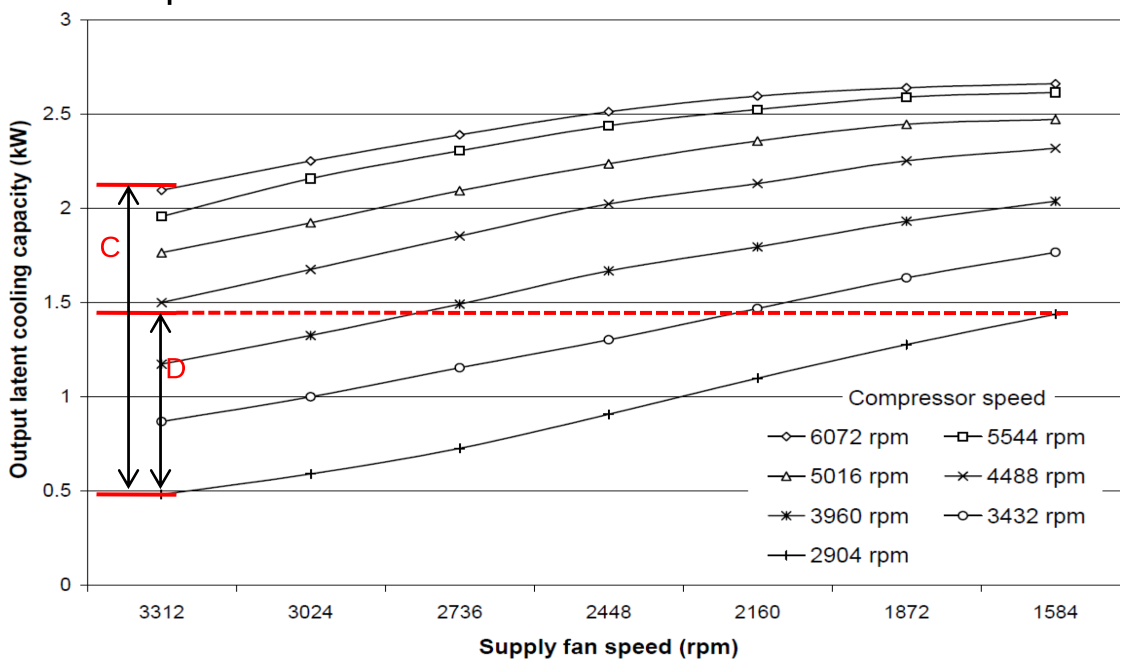
A < B

The influence caused by varying supply fan speed on the output sensible cooling capacity is more considerable than that caused by varying compressor speed

Development of the controller

- Proposed control principle

Operational characteristics:



Output latent cooling capacity (Ql) at different speeds combination

C: Latent cooling capacity change due to C speed variation

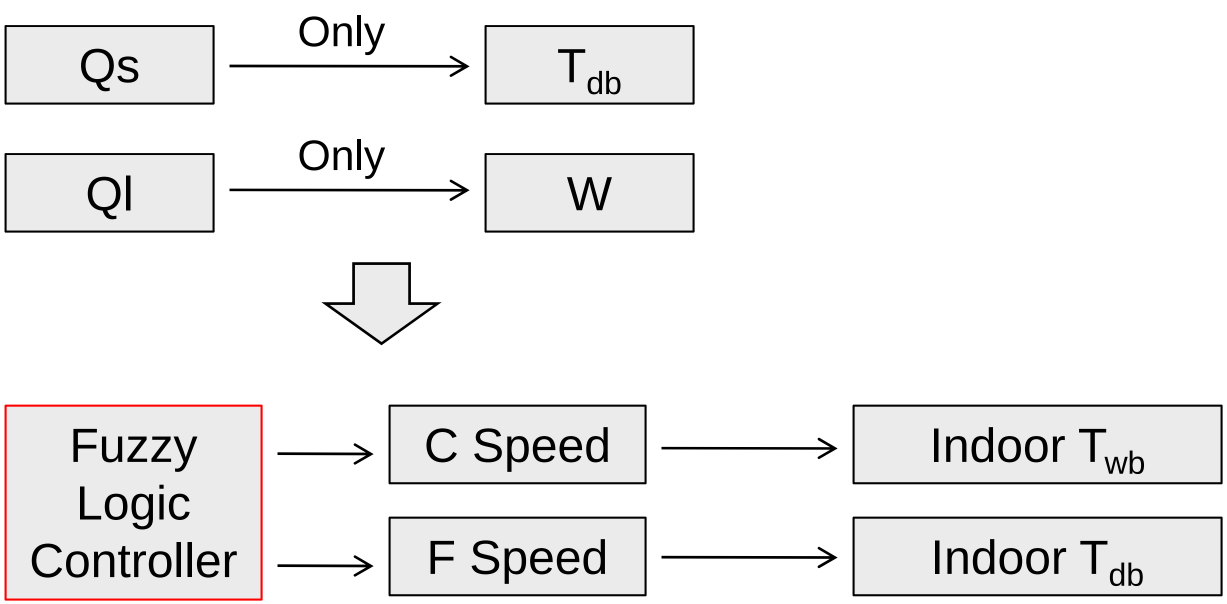
D: Latent cooling capacity change due to F speed variation

C > D

The output latent cooling capacity will be influenced more by varying compressor speed than by varying supply fan speed

Development of the controller

- Proposed control principle

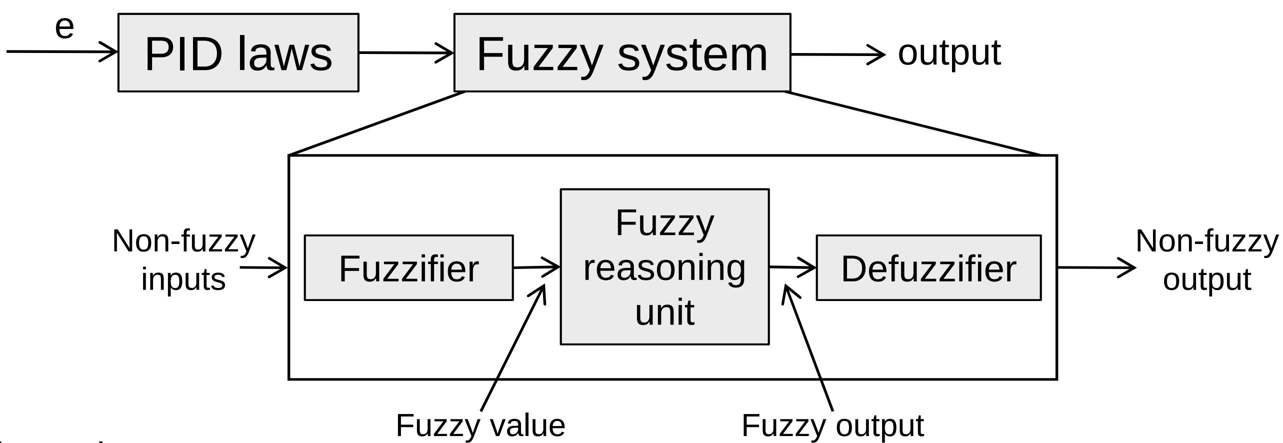


Controlled indoor T_{db} & T_{wb} determine the indoor thermal environment, realizing simultaneous control of temperature and humidity.

Development of the controller

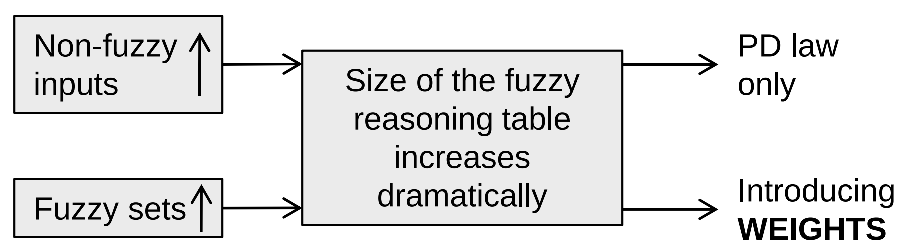
- Control algorithm

Conventional PFC:



Fuzzy reasoning unit:

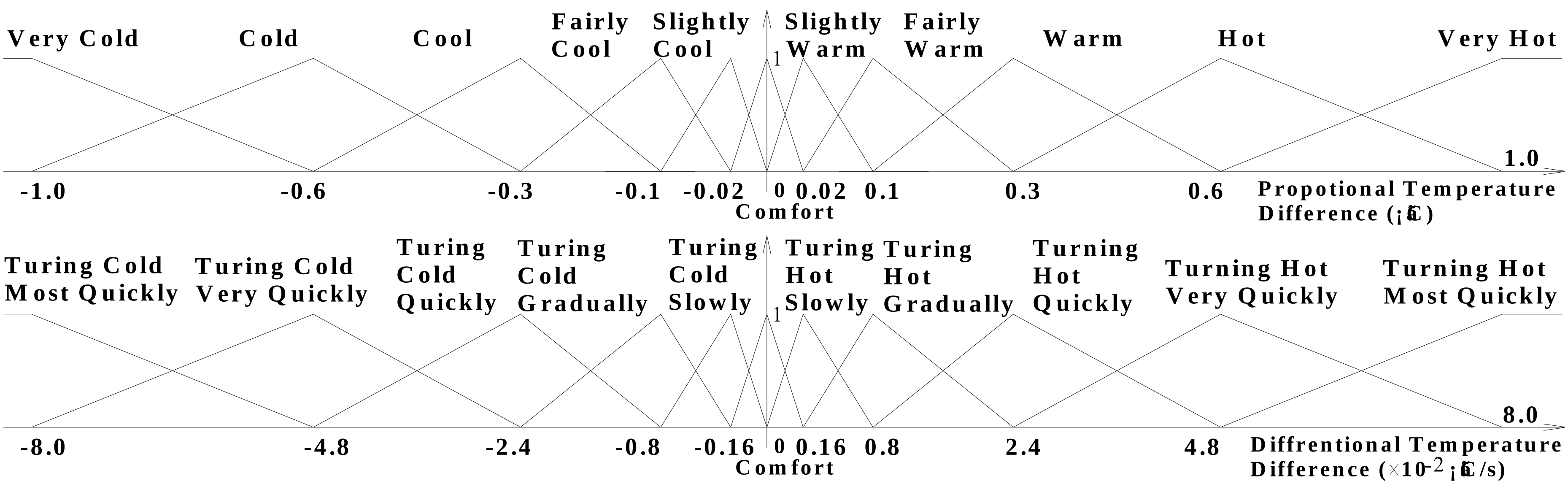
$e\downarrow \Delta e \rightarrow$	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NS	ZE	PS
NM	NB	NB	NM	NS	ZE	PS	PM
NS	NB	NM	NS	NS	PS	PM	PB
ZE	NB	NM	NS	PS	PS	PM	PB
PS	NB	NM	NS	PS	PS	PM	PB
PM	NM	NS	ZE	PS	PM	PB	PB
PB	NS	ZE	PS	PM	PB	PB	PB



Development of the controller

- Control algorithm

The membership function for T_{db} control:



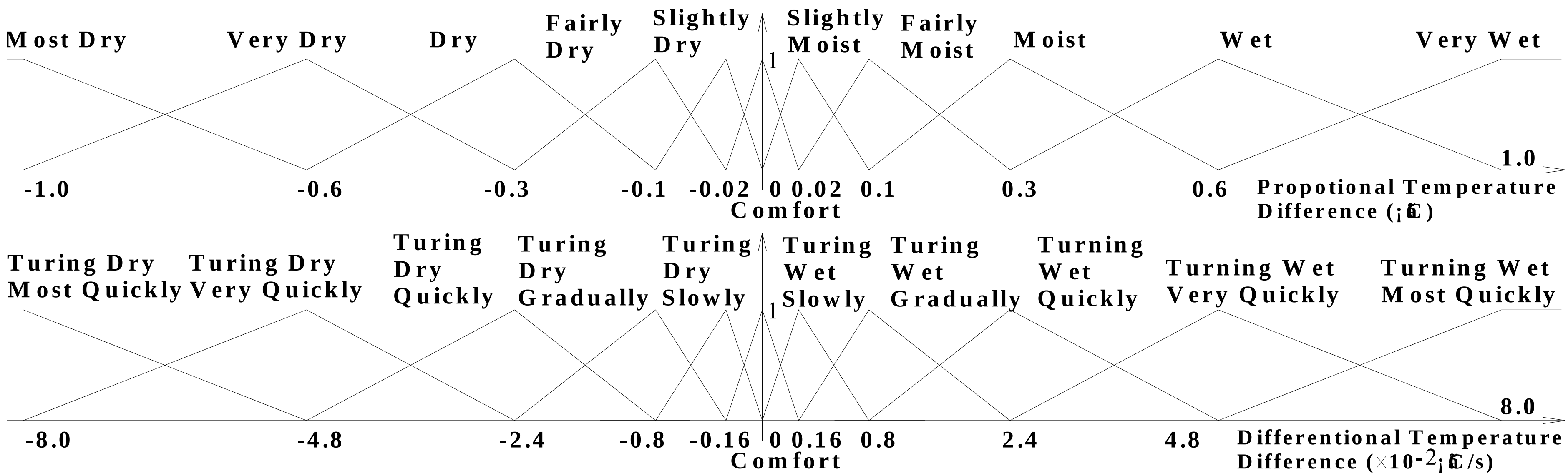
Very Cold…: Linguistic Variables, defined in different fuzzy sets

One membership function for each inputs of the fuzzifier: proportional temperature difference & differential temperature difference

Development of the controller

- Control algorithm

The membership function for T_{wb} control:



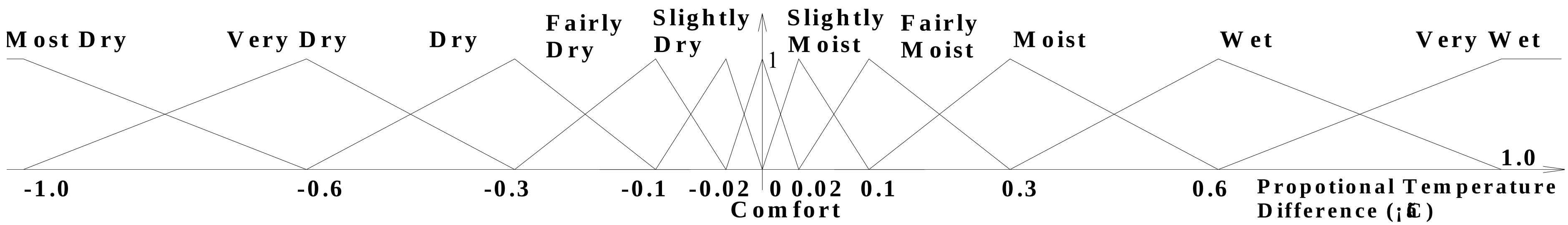
Most Dry…: Linguistic Variables, defined in different fuzzy sets

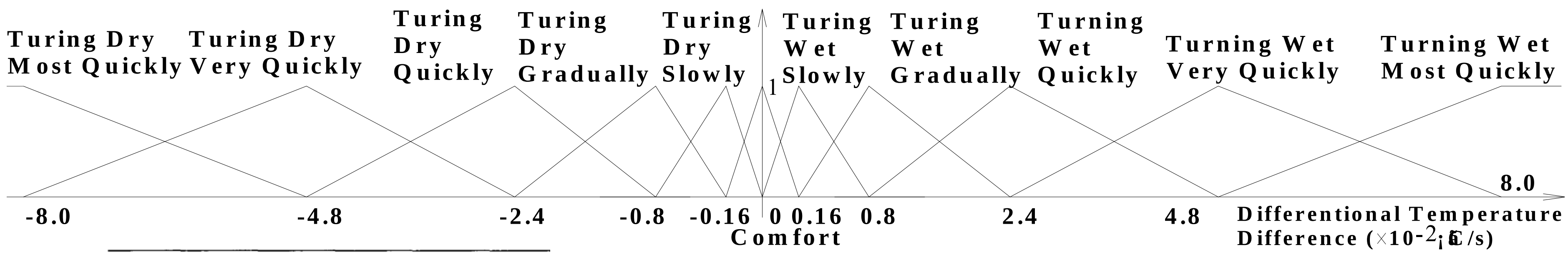
One membership function for each inputs of the fuzzifier: proportional temperature difference & differential temperature difference

Development of the controller

- Control algorithm

The membership function for T_{wb} control:





$e\downarrow \Delta e\rightarrow$	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NS	ZE	PS
NM	NB	NB	NM	NS	ZE	PS	PM
NS	NB	NM	NS	NS	PS	PM	PB
ZE	NB	NM	NS	PS	PS	PM	PB
PS	NB	NM	NS	PS	PS	PM	PB
PM	NM	NS	ZE	PS	PM	PB	PB
PB	NS	ZE	PS	PM	PB	PB	PB

⇨ 11×11=121 fuzzy rules for each control variable and most of them will be the same

Development of the controller

- Control algorithm

The Weights for different Linguistic Variables:

Inputs	Linguistic Variables and Weights										
ΔT_{db}	VH	H	W	FW	SW	Com	SC	FC	Cool	Cold	VC
	5.0	1.8	1.0	0.6	0.1	0	-0.1	-0.6	-1.0	-1.8	-5.0
dT_{db}/dt	THMQ	THVQ	THQ	THG	THS	Com	TCS	TCG	TCQ	TCVQ	TCMQ
	5.0	2.0	1.5	0.8	0.1	0	-0.1	-0.8	-1.5	-2.0	-5.0
ΔT_{wb}	VW	Wet	Moist	FM	SM	Com	SD	FD	Dry	VD	MD
	5.0	1.8	1.0	0.6	0.1	0	-0.1	-0.6	-1.0	-1.8	-5.0
dT_{wb}/dt	TWMQ	TWVQ	TWQ	TWG	TWS	Com	TDS	TDG	TDQ	TDVQ	TDMQ
	5.0	2.0	1.5	0.8	0.1	0	-0.1	-0.8	-1.5	-2.0	-5.0

$dx=\sum\left[f(n)_t \cdot \mathbf{W}\right]$ dx: degree of changes in C (dC) & F (dF), $f(n)_t$: grade of membership, W: weights for linguistic variables

Different inputs can lead to same dx and there's no need to build the 11×11 fuzzy reasoning table.

Development of the controller

- Control algorithm

The Weights for different Linguistic Variables:

Inputs	Linguistic Variables and Weights										
ΔT_{db}	VH	H	W	FW	SW	Com	SC	FC	Cool	Cold	VC
	5.0	1.8	1.0	0.6	0.1	0	-0.1	-0.6	-1.0	-1.8	-5.0
dT_{db}/dt	THMQ	THVQ	THQ	THG	THS	Com	TCS	TCG	TCQ	TCVQ	TCMQ
	5.0	2.0	1.5	0.8	0.1	0	-0.1	-0.8	-1.5	-2.0	-5.0
ΔT_{wb}	VW	Wet	Moist	FM	SM	Com	SD	FD	Dry	VD	MD
	5.0	1.8	1.0	0.6	0.1	0	-0.1	-0.6	-1.0	-1.8	-5.0
dT_{wb}/dt	TWMQ	TWVQ	TWQ	TWG	TWS	Com	TDS	TDG	TDQ	TDVQ	TDMQ
	5.0	2.0	1.5	0.8	0.1	0	-0.1	-0.8	-1.5	-2.0	-5.0

$$dx=\sum\left[f(n)_t \cdot \mathbf{W}\right]$$

$$C(t+1)-C(t)=\left(C_{\max}-C(t)\right)/10\times dC,\quad dC\geq 0$$

$$C(t+1)-C(t)=\left(C(t)-C_{\min}\right)/10\times dC,\quad dC\leq 0$$

$$F(t+1)-F(t)=\left(F(t)-F_{\max}\right)/10\times dF,\quad dF\geq 0$$

$$F(t+1)-F(t)=\left(F_{\min}-F(t)\right)/10\times dF,\quad dF\leq 0$$

C, F: percentage of the maximum rotary speed for compressor and supply fan, in %.

C_{max}, F_{max}: maximum output control signals for C and F, set at 90%.

C_{min}, F_{mim}: minimum output control signals for C and F, set at 25%.

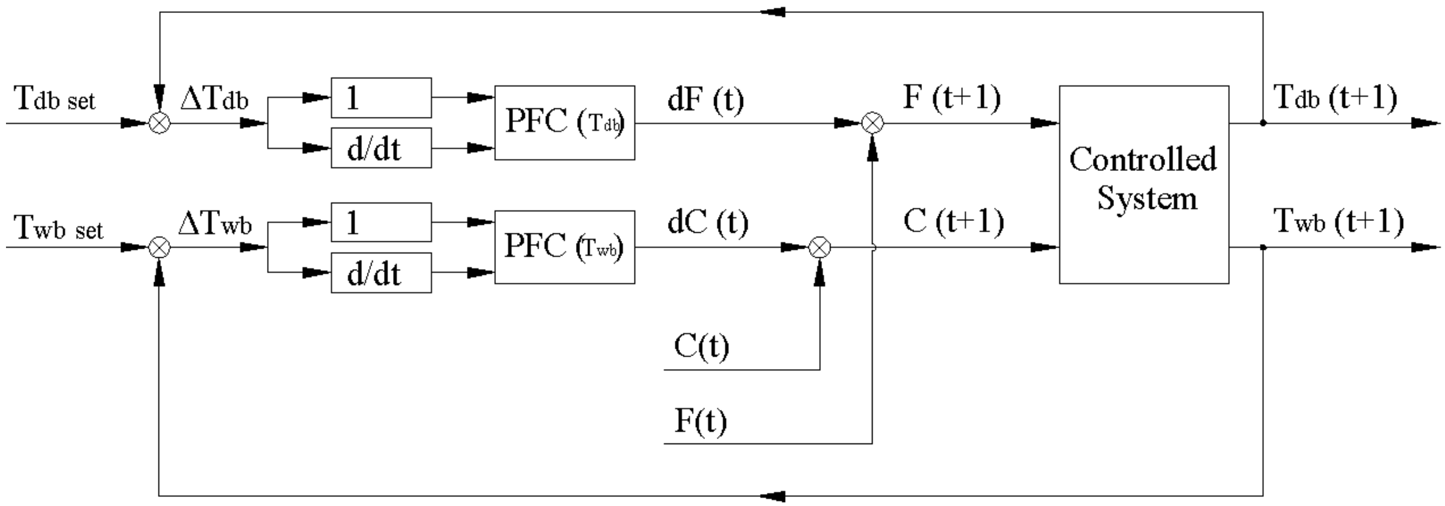
t: present time step.

No need to establish membership functions for defuzzifying stage

Development of the controller

- Control algorithm

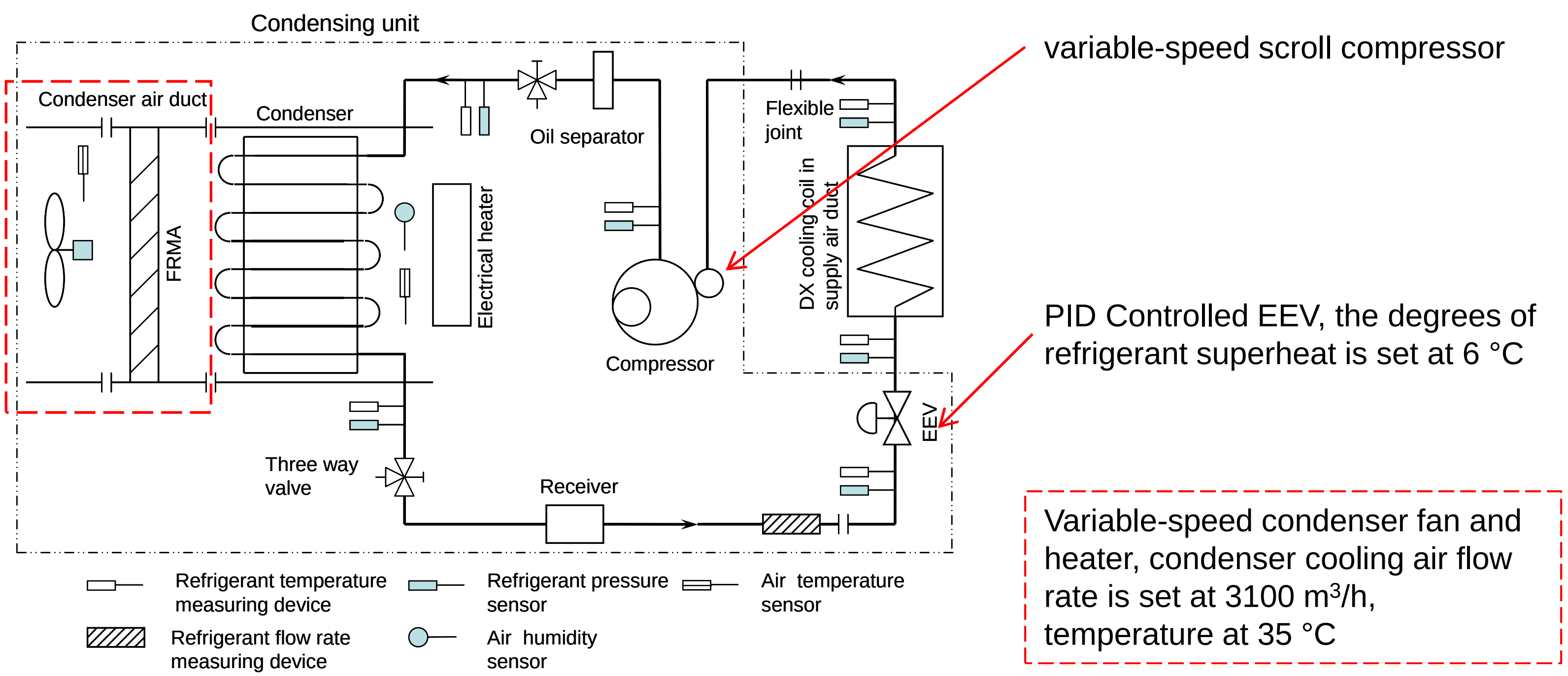
The completed block diagram for the controller developed:



The experimental setup

- The experimental VS DX A/C system

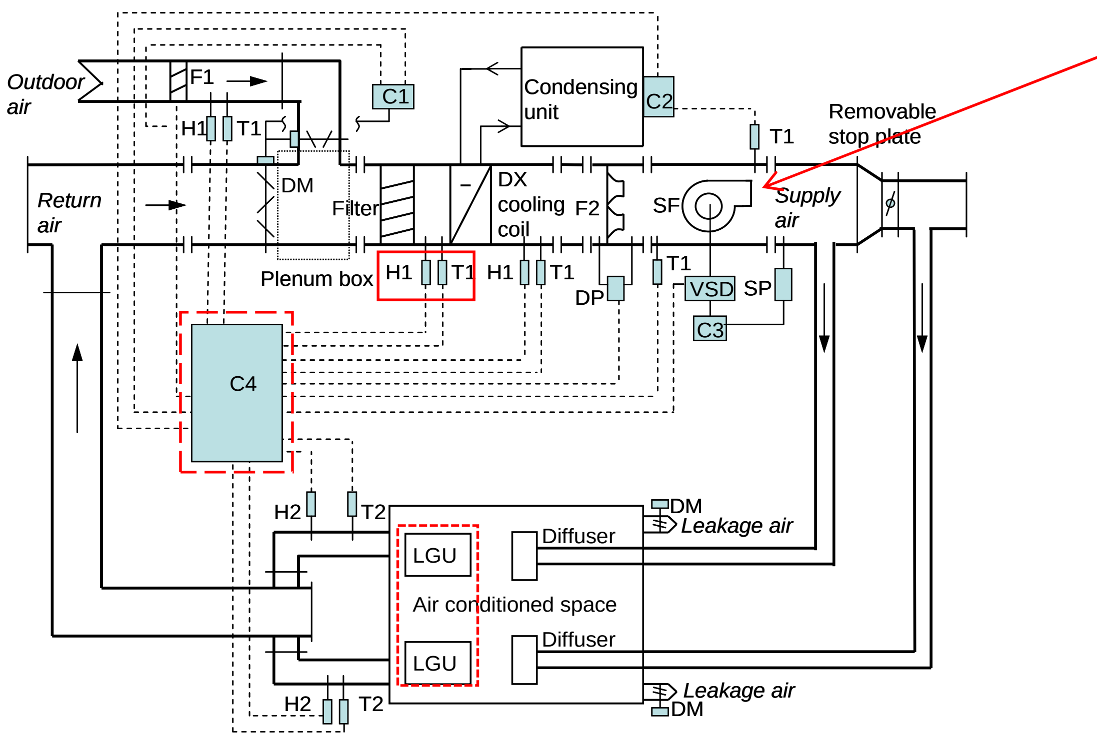
The DX refrigeration plant:



The experimental setup

- The experimental VS DX A/C system

The air distributing sub system:



Variable-speed supply air fan

Platinum Resistance Temperature Device, with pre-calibrated accuracy of ±0.1 °C

computerized data acquisition system, based on which the developed controller is integrated by self-programming

Load generating units to simulate indoor loads

The experimental setup

- The experimental conditions

The command following test: to test controller's ability of reacting to the changes of set points

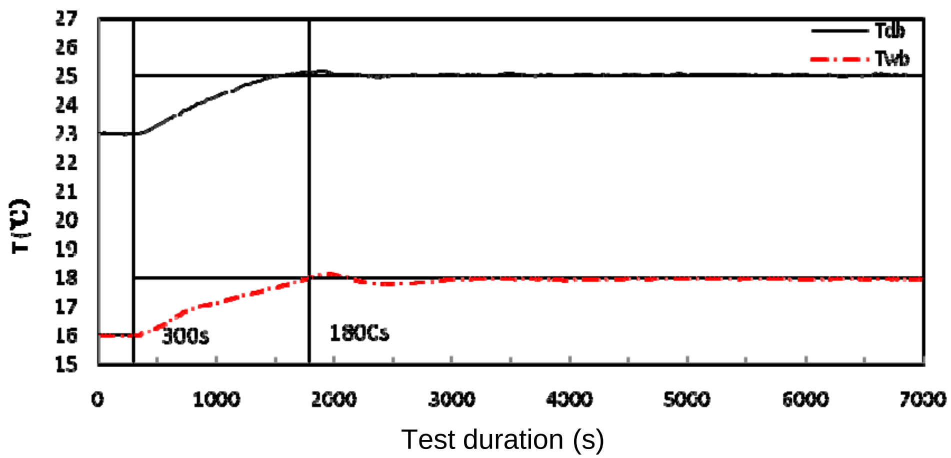
Former set points: T_{db} = 23 °C, T_{wb} = 16 °C → With fixed LGU outputs → Altered set points: T_{db} = 25 °C, T_{wb} = 18 °C → Controller performance

The disturbance rejection test: to test the controller's ability of resisting the disturbance caused by the variation of indoor cooling loads

Fixed temperature set points: T_{db} = 23 °C, T_{wb} = 16 °C → Former cooling loads: Q'_s = 5.26 kW, Q'_l = 1.42 kW → Altered cooling loads: Q's = 3.97 kW, Q'l = 1.15 kW → Pre-set activate condition → Controller performance

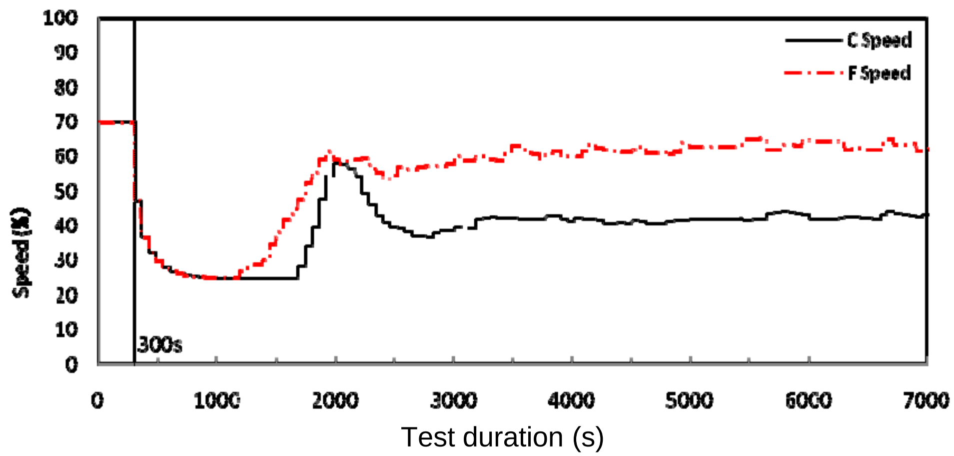
The experimental results

- The command following test



Temperature set points were altered at 300 s after achieving steady state

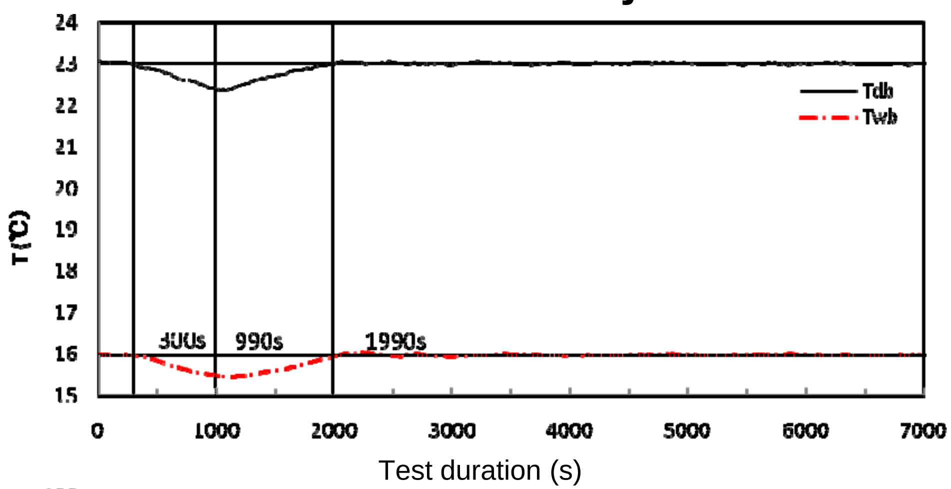
1500 s to settle at the altered set points and last stably for the rest time of test



Controller reacted immediately to the change of temperature set points regulating C and F simultaneously and finally maintained stably at new combination

The experimental results

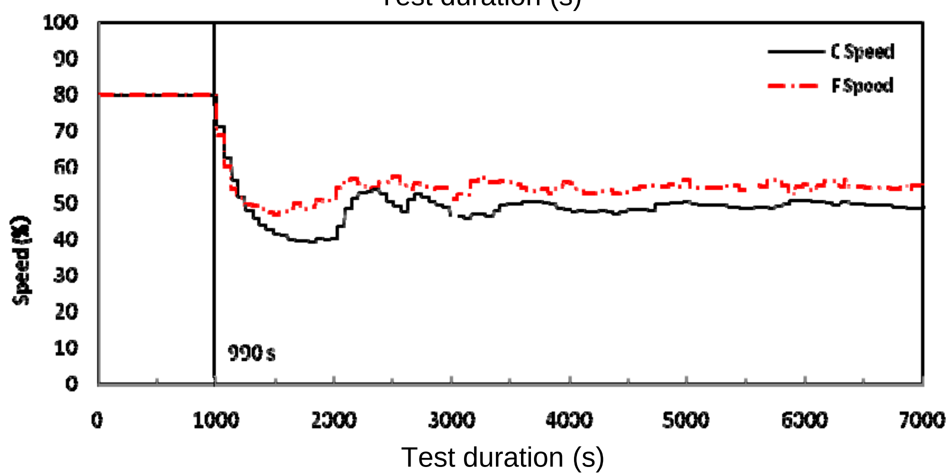
- The disturbance rejection test



Indoor cooling loads were altered at 300 s after achieving steady state

Controller activated when: both temperature changed by 0.5 °C

1000 s for brining both temperatures back to their fixed set points and maintained stably for the rest time of test



Controller reacted immediately when activated and regulated C and F simultaneously and finally maintained steadily at new combination

New combination of C & F speeds suggested the decreased indoor cooling loads

Conclusions

- A PD law based fuzzy logic control algorithm for a VS DX A/C system has been developed;
- The controller was experimentally validated by carrying out command following & disturbance rejection tests;
- Simultaneous control of indoor air temperature and humidity using VS DX A/C system is realized with an adequate control accuracy and sensitivity but simpler development;
- However, general methods for determine WEIGHTS should be studied in future.

Q & A

The END, Thank you!