Welcome to the first seminar of our seminar series in Climate, Air, and Health.

We have some online audiences joining us today, and before we get started, just wanted to let you know that this seminar is recorded, and later on, the recording will be posted on our center’s website.

On the monitor today, I have chosen assistant professor at Yale School of Public Health, and also the director of research.

So, it’s my great pleasure today to introduce our very first speaker, Dr. Drew Gentner.

Dr. Gentner is the associate professor in the department of chemical and environmental engineering. Also, the department of the School of the Environment.

He got his master and the PhD from UC Berkeley, and also he has been at the Department of Chemical Engineering since 2014, where his research group focuses on air quality, pollution, emissions, and chemistry.

And today we are very fortunate to have both Dr. Gentner and Professor Gillingham joining us online.
Today the main topic will be focusing on their recent paper, the Climate and Health Benefits from Intensive Building Energy Efficiency.

So without further ado, please. 

Thank you so much.

And my one request of the virtual audience is let me know if you can’t hear me clearly. I will try to speak loudly and through a mask, but just chime in if you’re having trouble and I’ll stay closer to my computer.

Alright so, you have both and Ken and I here today, and I wish he could have been here in person, but I get to present this paper that we worked on along with Professor Jordan Peccia in Environmental Engineering, a PhD student of mine, Colby Buehler, and former postdoc of Ken’s from the School of the Environment. So, this was a cool project that we were really excited about because it was a true interdisciplinary science where I was excited to work with Ken to do some energy modeling, and then bring that looking at outdoor and indoor air quality across the building envelope. And so, this brought in some expertise from Professor Peccia and I to look at air pollution and then extend it to the health effects.
This fell under the purview of our search center, hopefully I can click here. Alright, Michelle Bell has been the director of our search center, which I, Michelle Bell has been the director of up at the School of the Environment, and we’re in our last year at the center now. But the overall objectives of this were to look at energy transitions and look at the the wide range of sources related to energy production use, in the context of other sources that attract urban air quality and health. And then, we paid key attention to both transitions and key modifiable factors. So which things can we change, either through policy or personal choices, so that we can make smarter decisions related to transportation, land use, our power generation, and distribution networks. This had a number of different projects involved with it. Ken’s project was number one and mine was number two. We were doing this in collaboration with Johns Hopkins, and we had a couple other projects. And so these things, we’re focused on distinctly different areas of air quality where I was focused more on source characterization.
and measurements in project two and Ken was doing a lot of modeling on energy and emissions. So this project represented, and this paper, one of a couple things that we were doing has inter-center collaboration within a much larger center structure. And you can check it out online and see a lot of the other great work coming out of Michelle Bell’s group and others at Yale, Johns Hopkins, and our partner institutions. Which span some co-PIs at Johns Hopkins, and other PI’s, and Dan Esty, at the School of the Environment. So, onto this paper. So, now it’s like dive in and focus. This started, I can actually remember the workshop that Ken and I were at when we were talking about this research question. Thinking about how the climate and health benefits intersect when we look at building energy efficiency measures. ’Cause Ken’s group was thinking about how we reduce energy use in the building sector to reduce CO2 emissions and affect change for climate mitigation. And I started asking, well Ken, what about the indoor air quality on that?
You know, we’re gonna drop emissions of pollution outdoors from reduced energy production, but what happens with the building energy efficiency measures? And so, thus this project and this paper was born.

As a brief overview of where we’re going with this today, we start with the fact that buildings account for 40% of energy usage, a lot of our energy command nationally. So, it makes it a really prime target for climate change mitigation and producing both energy use and associated emissions. These are emissions of not only climate pollutants, but also air pollutants, slight particulate matter sulfur dioxide, carbon dioxide, nitrogen oxide. So, with these scenarios that I’ll show you in a moment, we looked at reductions in energy related emissions that would be occurring outdoors from power generation, and then translated that to its effects on indoor air quality. And, I’ll talk about that feedback loop in a moment. But, the approach here is to use the Yale-NEMS model, which Ken runs up at school of the environment,
to look at energy efficiency scenarios across the entire US housing stock. So we're not just studying one building; we model all the homes of the US and their changes over time with a lot of simulations and a couple models that were interconnected. Then we evaluated the outdoor indoor air quality implications. So how do the changes in emissions affect exposure and human health, both for outdoor and indoor exposure pathways, and look at the bad effects on human health, all of these together. So, I'll walk through this in a bit more detail, but we start from something where we take a reference scenario, an intermediate energy efficiency scenario for buildings and look at the changes in energy consumption and then test the carbon pricing scenario for those to see how that affects it. And we'll walk through this before, but if you fast forward all the way, you can see how we will then be able to look at projections in particular manner, emissions from that reduced energy use. So, the scenarios, without going into them in great detail,
although there’s a lot of information in the paper

and tech would be happy to answer questions,

looks at changes in both appliances and equipment

So we have all of this stuff indoors

for heating, cooling, cooking, lighting,

and other things like refrigeration

and those have a certain amount of energy use with them,

and that’s been a target of a lot

of governmental programs through efficiency.

You know, you can go and buy energy star things,

you see them when you go to the store,

and so, there are targets related to the energy efficiency.

And then in the building shell is where we start to look

at the interconnections at indoor air quality.

‘Cause the indoor environment is really complex.

The air that gets to us here,

or the air in your home navigates a lot of places.

Either through a forced air system or just naturally,

you have some penetration coming through the walls,

and some infiltration of air,

and the pollutants coming in,

and some ventilation of the air going out.
You may do that on purpose, opening you know, a door,
turning on a fan, or that might just be happening naturally,
and depending on the age of your home
and how well it’s sealed,
that could be happening at quite a high rate.
So, we look at the changes in the building shell
across a range of environments,
and we’re gonna talk more about residences today,
’cause that’s where we do spend most
of our time and a lot of our time,
a lot of our PM2.5 emissions indoors
occur in our residences.
So we’ll look at that, and we’ll look these scenarios
where we have existing homes and we look at changes
in efficiency that happen at slower incremental rates.
And then new homes that are built
to the newest specifications which follow these ambitions but demonstrated improvements.
So Ken’s model, which is the national energy modeling
system model that is the scale installation of this,
and the launch model developed by the US EIA,
covers a whole lot of things in the supply side,
convergence side, and demand side,
electricity, and integrates it together.
So, where we’re gonna focus on today for this paper is looking at the changes in the residential demand and commercial demand that are derived from these changes in energy efficiency. So if we change the design of a building, we are changing the energy in the air there, and that has feedbacks to reduce demand, to increase production and thus we have changes.

There are a lot of things that are in this model, and if you are a big fan of supplemental information sections and papers, I encourage you to check out the somewhere around 55 pages that exist in the paper with hopefully, every question that you might have about the energy modeling system and then hence, other work using this model. And so, if we look at the scenarios, you have the reference case at the top here in red that we play around the carbon pricing initiative on there.

Now we look at the intermediate energy efficiency, just for buildings here and see that that drops consumption down somewhat than a more optimistic one with without carbon pricing.
The direct effects on carbon dioxide emissions are shown over here where you can actually see a pretty sizable effect on overall carbon dioxide emissions just from building energy efficiency improvements.

So, this really points back to that fact that 40% of our energy use occurs in maintaining our buildings and in our buildings. Any change that we make here, a policy level has a pretty sizable effect on energy demand and related climate pollutants emissions.

This also has a sizable effect on air pollutant emissions like criteria pollutants for particular matter, NOx. SO2, VOCs, a sub effect on ammonia and carbon dioxide, excuse me, carbon monoxide, though today we’re gonna focus mostly on PM2.5, since that is driving factor of premature mortality, and what’s the key pollutant of interest for this paper.

So here we’ve defined what the changes are for each of these scenarios over this time rise extending to 2050 for the energy related emissions that are occurring outdoors. So if you wanna visualize it, what’s coming out of the smokestack for PM2.5 emissions.
So that’s gonna vary a little bit across the country where we generate that power, how we generate it. And so we’ll talk about that at the end of the presentation today.

We spend close to 90% of our time indoors, so we’re thinking about exposure to pollutants. We really need to be considering that indoor environment and how it modulates our exposure to pollution coming in from outdoors, but also how it affects how the design of that indoor environment affects our exposure to pollutants that are generated.

Now, I wish I had Jordan Peccia here today, so he could answer all of your COVID-related questions, relating to ventilation and filtration, because that is not my area of expertise. But you can take this admissions term here and think really about whatever pollutant or microbe you want, for your own work, and think about how that’s affected by the design of your home or the space that you’re currently in.

This is a box model. It is actually simplified considerably,
270 00:13:48.870 --> 00:13:53.040 to just a singular box representing a space indoors.
271 00:13:53.040 --> 00:13:57.390 But yes, there’s still one equation. For that, I apologize.
272 00:13:57.390 --> 00:13:58.950 You can ignore the equation if you like,
273 00:13:58.950 --> 00:14:01.030 I can try to cover it up and we can
274 00:14:01.030 --> 00:14:04.470 focus on the terms that are used here.
275 00:14:04.470 --> 00:14:05.720 So, I’m going to point out a few things
276 00:14:05.720 --> 00:14:07.380 on how the model connects,
277 00:14:07.380 --> 00:14:10.470 just to try to show how this all comes together.
278 00:14:10.470 --> 00:14:15.470 So first thing, we have recirculation with a filter.
279 00:14:15.660 --> 00:14:18.780 Now you’re predominantly talking about HVAC system.
280 00:14:18.780 --> 00:14:22.110 So, forced mechanical air filtration system
281 00:14:22.110 --> 00:14:23.970 that you would have in an indoor building.
282 00:14:23.970 --> 00:14:26.460 You have them here, your apartment,
283 00:14:26.460 --> 00:14:28.320 perhaps up the east rock,
284 00:14:28.320 --> 00:14:33.240 that was built 80, 90 years ago may not have that,
285 00:14:33.240 --> 00:14:37.950 or some newer builds don’t have of course, HVAC system,
286 00:14:37.950 --> 00:14:39.750 but that is where you would have some
287 00:14:39.750 --> 00:14:42.213 active particle filtration that’s occurring.
288 00:14:43.200 --> 00:14:47.410 Now in the the era of thinking about filtering for
289 00:14:48.930 --> 00:14:51.990 you know, viruses and other microbes doors,
290 00:14:51.990 --> 00:14:53.940 whether it be COVID or otherwise.
291 00:14:53.940 --> 00:14:56.370 We’ve started to put in some affordable air filters,
292 00:14:56.370 --> 00:14:57.900 so you could also think about that,
293 00:14:57.900 --> 00:14:59.550 but we’re predominantly looking at this
294 00:14:59.550 --> 00:15:01.203 in terms of the HVAC system.
So, on the other side here you have air coming in. Infiltration is that, what I was talking about was coming through the cracks. You have bad windows, ceiling, it’s an old building. You know, there’s some areas where air just gets in. If it’s a newer, newer building, those seals tend to be better and better, and you have fewer spots for air to infiltrate from outdoors. But then you have this, and you have a penetration factor in there for how much particles get through those little cracks. So they can get stuck on the way. It’s kinda like a filter like our mask. And you have natural ventilation, so you open the window because it’s hot out or if you burnt toast, it’s gonna provide some natural (indistinct). Indoors, you know, the main thing is you have emissions for cooking, you burn a toast or just you know, regular, you were frying up some eggplant for dinner, and that generated some PM2.5. Number of appliances while you’re cooking, actually have a pretty sizable PM sources, but that depends a lot on cooking style, and I forget you’re affected by some
of the filtration over your stove.

We also worked into the model, the two loss terms of the deposition of the six.

So, particles go to surfaces and also they could be meddling outside.

But we’re thinking today about, what is the changes that happen to these terms,

and how it affects the concentrations indoors. But built within this is thinking about the housing stock.

So Colby Buehler, a PhD student in environmental engineering, did a literature view of the US housing stock working with Peg Long from School of the Environment
to determine the filtration flow rates for homes’ HVAC, and the fraction of homes with HVAC systems

and also the quality of filters in there. If I was, if we were all talking about this a couple years ago,

you would probably not be very familiar with the quality of filters that exists up in these systems.

But there’s this whole rating system for 2, 4, 6, 8, 10, 12, 14, and it goes up to 16, then we get the half a grades,

and that has a major effect on the efficiency of those filters and the filtration of particles, doors or air barns, microbes or dusts or anything else.
And then the infiltration and natural ventilation rates are also affected by house, home aid. So you think about infiltration, a home with more cracks, more gaps, has more infiltration through those penetration points. Then, the residential energy demand consumption survey was used to determine appliance usage across all homes. So, we could look at the distribution in homes. Obviously, it comes down to how many people live in a home, but some of us are cooking all the time. We cook at home every single night, we use the toaster while we’re using the stove, while we’re using the oven. And some people, you know, will stop by and, you know, pick up something from the local falafel shop for dinner most nights. So, that’s gonna have a huge effect on this admissions term, and it’s going to propagate through this whole system, as you’ll see later. So we then model over time, the changes in the US housing stock up through 2050 for this analysis. And changes in the building type, which includes the volume of home, sizes are going up,
the amount of new homes that are built and the characteristics of those homes with respect to the installation of HVAC systems and filter types and all of that.

So, and ultimately, the big effect that this has with the changes in the housing stock and energy creation or energy efficiency scenario is on this infiltration.

So, how much ventilation occurs in your home without you actively doing that. You didn’t turn on the HVAC system, you didn’t necessarily open the window, but you have some pressure changes in home, and air is also very good at moving through cracks and things, and it will bring (indistinct) with it.

If any of you just moved to New Haven, wait until a nice cold day, go stand near a window at an older building, and you’ll certainly feel that cold air moving through some of those gaps. I know I had that experience when I first moved to New Haven. I’m gonna talk about something not, I won’t refer to it as a Monte Carlo analysis over and over again but I want to make the point that to constrain the uncertainty in the study,
Colby Buchler ran this a lot, a lot, a lot of times.

Thousands upon thousands, across the entire US housing stock.

So if you go through and you simulate a whole bunch of homes with this model, and you look at all the different conditions you can have,

what is the net outcome of those?

So again, we’re not just talking about one home with one set of conditions, or a small perturbations that we will look at one or two things.

But trying to put those all together so we can show sensitivity to these different features.

So, the HVAC system and what it means for emissions,

and how does infiltration change with energy efficiency measures, and the age of a home.

So questions before we start moving out to results.

If not, good work, you just got through like lecture five,

or six of my class on box models so that’s great.

We do have a student.

Yes.

Yeah, I’m just, how confident are you in modeling how the housing stock group change also changes in appliance?
Like out to 2050, or did you use different scenarios?

So, actually Ken,

It’s phone a friend time already.
The question was how confident are we in the changes

of the housing stock and appliance shifting over time,

and how are those scenarios, model there,

are there multiple scenarios in the NEMS model?

That’s a a great question.

What we do is we use,

so it’s built into NEMS and NEMS explicitly

is modeling housing stock changes

based on trends in the past.

We easily could do uncertainty analyses over those numbers.

I think that kind of, main takeaway on that

from my understanding is that those aren’t gonna be

the driving forces of our final results

unless you are really dramatically

changing the housing stock.

And I know this from another paper, not this paper.

You’d have to really dramatically change

the kind of core housing stock itself.

And the reason for this is that there’s

a lot of inertia in the housing stock.

So, there may be changes in how well it’s insulated
and you know, broader retrofits in how they’re done. But the basic stock itself is quite slow moving. That said, I think you should take anything out to 2050 with a grain of salt, maybe a very large one, and so I’m not gonna hang my hat on the exact numbers on the nature of the housing stock, ’cause it’s the full nature of the housing stock that’s being modeled. And I’m not gonna hang my hat on the full nature of the housing stock in 2050. But I’m pretty confident that the numbers are gonna be pretty close to right in 2030, 2035, in that range and maybe even now out to 2040, just because of how much inertia there is in housing stock. But only a small amount of turnover actually occurs. I’d have to be more concerned about appliance type. It seems like, you know, we have possible scenarios of complete electrification, right, by 2050. Versus not doing that and still having a substantial number of gas stoves for example, would have a large effect on your conclusions. So, the question’s on
the changes in appliance tech Ken,
and I'll take a quick shot at it and let you add to it.
But, so that does get discussed in the paper.
We don’t include specific perturbations but we talk about
how stoves changing up,
changing to full electrification could affect that.
We get into some really interesting questions then about where the emissions coming from.
Are they derived from the use of natural gas, or are they derived from the process itself?
If I, like your toaster is generating PM, based on what you’re doing with it,
not so much based on how much power,
obviously, if it’s not a natural gas toaster.
But if we’re thinking about a stove, some fraction of that PM comes from the actual burn itself.
But if it’s a reasonable stove,
the PM is probably coming more from the cooking itself.
And that’s a really interesting question, and one that there was a cool paper
that came out of Stanford looking at the emission rates,
although they were thinking more about methane in particular,
which is where you have a huge impact on (indistinct).
So, on the climate side is where I think
we can see a large effect of
short lived climate pollutants there. And we do build in a few scenarios in there to look at some of these changes and try to bound them.

Ken, can you grade my response and add anything to help there?

I liked your response. I wanna add a few things. One thing is this paper is explicitly about improving the efficiency, given the existing forecasted technologies in NEMS. In our scenarios, it’s not about fuel switching, and I think fuel switching is a really important question and we actually have work underway to explore that question, where we’re looking at scenarios that actually would allow fuel switching. So, say switching from burning natural gas in your range, to an induction range, right? Electric induction range.

So, that type of fuel switching, we hold constant in this. So we don’t, any trends that are in the baseline in NEMS, we continue, and we don’t focus on those, our scenarios are very much about improving the efficiency. I think in reality, you may end up seeing both
happening somewhat at the same time. But it depends on the policy direction. You could see a world in which you do see a lot of fuel switching and not much efficiency or vice versa. And I think from a intellectual perspective it’s really helpful to parse those out, and understand them separately. So that was sort of the, some of the thinking behind it, how it plays out in what we do here in this analysis. But it’s a really great question and a really important point. I think it’s becoming increasingly important as we move forward because of the IRA, you know, the recent act, and other efforts to lead to electrifying the home. There’s been a real push in that direction, so I think, but this framework that we’ve set up is reasonably well suited with some modifications to understanding the implications of some of those questions, too. Right, thank you for the questions. Johan, to answer your question,
the exact materials that are used to change the building efficiency in terms of insulation are not explicitly worked in here, but they are part of changes in building shell efficiency.

So we look at, in the paper we discussed, how changes in installation versus changes in building ceiling could affect the ultimate outcome.

Alright, so participation time. How many people in the room have an HVAC system in their home or apartment?

Alright, so we’re talking, alright, so that number came in at about 10%.

I don’t know, hands were really kind of low on there.

So, now is where we have like, a choose your own adventure moment in the presentation.

So for those who are in homes that do not have,

it’s gonna come back I promise. Alright.

Recirculation with filtration, here are the overall results for the entire US housing stock,

comparing the reference scenario here in the reddish orange color to the intermediate case in blue.

And then green is the optimistic energy efficiency case for buildings.

On the bottom here, you’re looking at the indoor emissions percentile.
581 00:29:11.010 --> 00:29:13.023 So the far left,
582 00:29:14.310 --> 00:29:15.690 this is the person who picked up
583 00:29:15.690 --> 00:29:18.514 falafel for dinner every night then.
584 00:29:18.514 --> 00:29:21.750 Hopefully, they got different toppings but they
585 00:29:21.750 --> 00:29:24.270 did not do much cooking in their home,
586 00:29:24.270 --> 00:29:27.180 and breakfast they got on the way to campus.
587 00:29:27.180 --> 00:29:28.290 And on the far right here,
588 00:29:28.290 --> 00:29:31.170 this is the person who wanted deep fried
589 00:29:31.170 --> 00:29:36.030 cauliflower three times that week, and is cooking a
590 00:29:36.030 --> 00:29:37.560 lot.
591 00:29:37.560 --> 00:29:38.730 Maybe it wasn’t deep fried cauliflower,
592 00:29:38.730 --> 00:29:40.950 but you get the point.
593 00:29:40.950 --> 00:29:44.190 Here is where there’s a lot more indoor emis-
594 00:29:44.190 --> 00:29:48.690 sions.
595 00:29:48.690 --> 00:29:51.167 And on the far left,
596 00:29:51.167 --> 00:29:52.380 this one you can think as a cleaner home
597 00:29:52.380 --> 00:29:54.540 just in terms of the indoor emissions.
598 00:29:54.540 --> 00:29:56.280 So, if you’re all the way here on the left side,
599 00:29:56.280 --> 00:29:59.163 you’re seeing actually a benefit
600 00:30:00.360 --> 00:30:03.750 compared to the reference case of building
tighten.
601 00:30:03.750 --> 00:30:08.670 So reducing that infiltration actually yields
602 00:30:08.670 --> 00:30:11.910 you a benefit.
603 00:30:11.910 --> 00:30:16.350 And the reason is, any of the PM that is
604 00:30:16.350 --> 00:30:20.940 is not making it indoors because your home
is sealed off.
You have a very, you have a tighter box that you live in. So you are just living with your own emissions, and you don’t have as much infiltration of particles from outside. If you move to this other side here, and you can see where it is worse than the, oh excuse me, this is with recirculation. I said before this is without, this for the 10% of you that have an HVAC system. Here on this side is showing if you’re doing a lot of cooking indoors, you actually see a penalty from those energy efficiency measures. 'Cause now you have bottled up your home, you have filled all the cracks, maybe not every last one of them but you haven’t improved the ceiling through your home to the point that you spend a longer time with any of your emissions indoors.

So, the bummer is that that toast that you burnt lingers longer, or it could be a continued source of something, if you had a bad pilot light or something else in your home then that continues, or persists along.
So, when you’re looking at this, the reference case models the building stock without any changes from the energy efficiency scenario. So what is the current inertia, and everything that we talked about. And then this represents the change, where the left shows some benefit, and the right where you get about the reference case line shows a detriment indoors. So, for those of you, the 90% in the room that don’t have an HVAC system, or other recirculation with filtration, this is what it looks like. So, everything is the same here. The only difference is now we’re looking at the 38 to 45% of homes depending on the scenario that have no filtration or HVAC system at the home. So, now you can see this effect is exacerbated. There’s a smaller fraction of homes that see a benefit for their indoor pollution from these energy efficiency measures, and a larger fraction that get greater exposure to particulate matter because they spend more time with those emissions. So this shows two things, the importance of the indoor emissions
in determining your indoor exposure and target ventilation there. And the importance of recirculation with filtration, just for PM2.5. Yes?

This might be a silly question, but, this is like the, it’s hard for me to believe, to understand how building efficiency have that much impact over HVAC. Like I would think that homes have the circulation system would be filtering air more than like, having cracks in the wall, and like, not as great of efficiency would like, have an impact on this. Does that make sense?

Like, just looking at the reference line there. So like, if there were no improved efficiency in the building, you would still be having this kind of like, being close to the one to one line if you had a lot of indoor air emissions. But then, you improved, like how is the HVAC not filtering?

Improving? Yeah, I guess, or I guess, yeah. I just think of it as like constantly pulling air out, and like, pushing fresher air back in. So that was the, how is the increased
efficiency of a building making that almost worse.

Does that make sense?

It does, and it’s actually a great opportunity to make a clarifying point here,

that in the current paradigm of building temperature,

climate control, infiltration, this is a closed one.

Your HVAC system takes air, conditions it, and puts it back into your home.

So, it comes down to the efficiency of that filter,

rather than if saying, we’re gonna give you completely fresh air from outside,

to get rid of all our air

from the inside and put it outdoors.

This is where we’re starting.

We’d be thinking about like, next generation things.

Is there any opportunities to get fresh air while

not paying the penalty for having to completely

recondition, well I say recondition,

I mean, change the temperature of all the air coming in.

Perfect, yeah.</n> <v Dr. Gentner>No problem, that’s a good point to clarify,</n>

so thank you for that.

The only major everyday example for a lot of us,
or exemption to that would be in some of our labs,
we have a fume hood obviously,
we'd dump all of that out the building,
we don't recirculate that.
And there were some changes in various buildings,
like on campus I know where the percentage of fresh air
versus recycled air has changed over the past couple years.
So, alright, so,
If we think about this effect,
this is looking at the overall effect,
the entire housing stock for these two cases,
or two types of homes across old and existing.
Then we have this result where we end up
at steady state having higher overall concentrations.
If you wanna visualize this more,
as what's happening for any singular event,
you can think about the response time to something.
So if you just look at this as a singular case,
let's say here,
you, oh, stick with the burning toast scenario,
you generated really high concentrations
and then you stopped.
How long does that take to decay down?
And specifically, we think about that as the folding time,
so down to one over just 37%, to keep it going on.

And, so we look at that in the different scenarios

with and without filtration.

One other point, actually I wanted to make

about your quick filtration question

we’re not recirculating air

at a range of like, the entire house

over 6 points or something.

During COVID we increased some of

those ventilation rates for public spaces.

Marketing air exchange rate of 4 or 5,

those are probably the goal ones.

So air exchange per hour,

but we’re not changing everything.

here with the filtration and recirculation

for dropping it quicker,

in the cases of having an HVAC system.

And then you can see, you know,

as we tighten up the building more and more

in the optimistic energy efficiency case,

you know, that time that you’re spent with

of be it toast or whatever else,

that happen indoors increases,

and you can see the theory we’re approaching.

(indistinct)

So, that helps to visualize what’s happening,
just in terms of the time.

Hopefully, that’s a useful comparison.

So, but we know that the system is sensitive to outdoor PM concentration.

So, we did all this modeling, and then we did a couple case studies

within it across all different outdoor PM concentrations,

and looked at how the system responded to outdoor PM.

Because if we go back to that box funnel,

and I won’t put it back on the screen again,

but you know, remember we have

the concentrations of PM outside,

and that’s trying to come in

and then we have our indoor PM and that’s going out.

So we have this really complex game

that’s happening over the building.

And so, if we keep our indoor emissions on the bottom.

So, again, this is the home of the most indoor emissions

and this is the home of the least,

and we look at the outdoor

concentrations on the Y axis here.

So this is the ambient outdoor PM2.5 concentration.

The national average is here,

the annual standard is here,

and then the 24 hour standard’s up there.

So, depending on where you live,
and even time of year or if it’s a pollution event, you’re going to fall on different spots.

This graph vertically and that ratio of what it is in the optimistic energy efficiency case, versus the reference case is shown here. Where red has just energy efficiency measure increasing the indoor concentrations, and blue shows it decreasing the indoor concentrations. And that’s just because again, here you are preventing the PM from outdoors coming in. Imagine it’s a wildfire scenario, and you’re living in the northwest and your home is really tightly sealed, so your concentrations are really high outdoors, and you’re up in this space where your home is more well sealed so less stuff gets in. If you go all the way to the right of this and you’re in cleaner conditions outdoors, but you have a lot of indoor sources, now that tighter building with with less infiltration actually increases your indoor content. So point says, interesting interplay between outdoor and indoor PM and how that interacts.

So, if there’s anything you take away from today, whether it be for particulate matter
or other atmospheric public health considerations,

I hope it’s thinking a little bit about that interaction between outdoor and indoors.

So, in summary for this slide,

which it literally has a lot of different information on it and colors.

The impacts of these energy efficiency measures on indoor air quality are partially dependent on outdoor air quality, in addition to the in-home emissions.

So if you were to translate this to Delhi, or another city that has higher outdoor concentrations,

have to help how you approach this.

There are some studies that were done,

just looking at a few homes back in Beijing.

And, probably like a decade ago,

at Berkeley looked at the changes in home infiltration and ceiling and how that actually affected imperfect air concentrations to outdoor ratios.

So, it does have an impact in other locations, and it can be different than what we’re showing here.

Okay, so to wrap this up and look at it together.

I said we wanted to look at the outdoor effects and the indoor effects.

We spent a little bit more time on the indoor stuff today,
but we get this huge gain from the reduction in outdoor PM2.5. This is really like the energy related PM2.5. So we've dropped the energy demand for buildings considerably with the cases here. So intermediate, optimistic, optimistic with carbon pricing. And so we have a few benefits in reduced premature mortality that’s avoided in 2050.

We just talked about the complexity of indoors. And so overall, we see a detriment indoors but this is not for every home, ’cause there’s many homes that see a health benefit from the energy efficiency improvements based on this modeling. And so it’s those high emissions homes, high indoor emissions homes that drive the overall effect negative.

So, those graphs that I showed you before that had the lines across them for HVAC and non-HVAC were showing that, you know, there’s a fraction of homes that see a detriment and need to see a benefit from this as well. But overall, the indoor effect offsets this positive outdoor effect, but it’s weighted towards a subset of homes and a subset of the population.
We look at this on net for those three scenarios: intermediate, optimistic, optimistic with carbon pricing. We see that we get a net benefit from energy efficiency for avoiding premature mortality for PM2.5. This is stacked on top of all of the benefits that we get from the reduced climate pollutants. So, we get a climate benefit in terms of reduced CO2 emissions, and we get a benefit in terms of improved public health. And that’s driven by a large decrease in energy-related pollutant emissions, and to some degree, some of the homes that have poor indoor air quality. But we do see some of the negative effects on indoor air quality overall. That’s what I said in summary. And then, we wanted to test how the effect of HVAC usage or filtration system’s effectiveness. So, if we look at the case where we actually upgraded all homes to have 100% good HVAC systems. So boost that investment up, actually increases the health benefits that occur. So, basically if we improve indoor air quality through improved filtration indoors at PM2.5, we can achieve a larger benefit there.
This can be put up as a summary.

Here, where reductions in outdoor emissions, yielding that benefit across the entire building stock.

And, the observed changes indoor air quality, due to these energy efficiency improvements, really require us to think about improvements to our indoor PM2.5 emissions, the targeted ventilation of those emissions.

So, better ventilation of cooking emissions, improving the PM2.5 filtration efficiency.

So, upgrade your filters, get better efficiency for those of you who can.

And then, careful consideration of these energy efficiency policies and how we look at ventilation in buildings.

And this is yet another time where I wish I had Jordan Peccia on the line as well, to make a few comments on that.

Because it is a really interesting, important topic for design, building ventilation for quality of life.

We present this today in the paper, through the lens of PM2.5.

And we include some discussions in the paper about different pollutants.

I think for indoors, and we did it in various amounts,
so that goes through the range of criteria pollutants.

We can even start to think about radon in some areas of the country. We can start thinking about disease transmission.

No worries, it has nothing to do with this paper, but it does come up against the space where we think a lot about building design, and filtration and ventilation.

The graduate student who was working, sorry, the postdoc who was working on this, modeled it spatially and across various geographic regions.

And you can see for the intermediate energy efficiency pace, the optimistic one. And then when we employ carbon pricing and carbon pricing with the optimistic case where the benefits occur.

And these differences come down in many ways to how power is, generator, how electricity is generated in various areas of the country.

So where we see some of the largest benefits depending on the case. So, carbon pricing is gonna have a sudden different effect than on the optimistic case on it’s own. It’s going to change the
underlying fuel that we’re using for generator outlets.

So, you know, we think about the midwest and the northeast here, the types of fuels that we’re using for power plants.

So, using that demand is going have a larger effect, where there’s a higher amount of renewables.

So, in summary, and then we’ll open it up to questions with whatever time we have.

The study used the NEMS model coupled with The Monte Carlo analysis. Indoor air quality box model across the entire US housing stock.

We see a 6 to 11% reduction in carbon dioxide emissions. and a 18 to 25% reduction in outdoor energy-related emissions of PM2.5.

So, this is not including other PM2.5 sources. These reductions are complimentary with carbon pricing.

It takes the pressure off as we’re trying to decarbonize electricity going forward.

So these building event, energy efficiency measures provide a huge opportunity, but they require attention to indoor PM2.5 emissions, and improving PM2.5 filtration, and thinking about how we implement these ventilation-grouping policies.
that get at some of the nuances that you're talking about with fresh air exchange and energy recovery. And so, in all the majority of homes see improvement or little change to indoor air quality, with these energy efficiency improvements. A subset of homes have increased PM2.5 concentrations indoors, which there, overall are driving health effects going forward there. And we're seeing that benefit in total, outdoors.

So with that, we are at 12:50, so I'm happy to take any questions that people have.

I have Ken here to answer all the tough ones that I can’t or don’t wanna answer, and thank you so much for you time today and for the invitation.

So, I think we have two questions. Okay.

I guess each student already prepared some questions. So, and what would you want to ask?

Could you go back to the health impact slide? Hey could you go back to the health impact slide?

Sorry, yeah, thank you. First, if there was a bar on there for no, like without the energy efficiency,
like, whereabouts would it be?

So this is all comparisons.

So to the current trajectory.

So, this is the changes that occur on top of whatever we expect to happen in the absence of these standards.

I guess I didn’t consider, (indistinct)

It does.

Though, it doesn’t include a distribution of clients saying you know, across different subsets of the population who is spending more or less time at their residence.

But it does scale for them.

I was wondering if there are plans?

to put your study off to different groups, so looking at how (indistinct)

You know, what are the,

are there plans to study the specific (indistinct)?

Yeah, so-
The online audience is gonna hear the students-

Oh, okay.

Yeah the first question, prior to that was about the half of the slide that’s up.

What the zero line is,
and that’s the comparison to the reference case. The question was just posed is is how much does or do we have plans for another study or set of studies looking at gas phase pollutants? And so we include some commentary in the paper about some of the factors that need to be considered. And it does, it comes down to how much the emissions current indoors versus outdoors. The other for Nox, you already really got out one of the huge factors there, is there is no, there’s not a readily available filter that we already have in all the homes that filter NOx with the kinda efficacy that we have with particle filters. So, that adds a really interesting thing that makes it so that HVAC system doesn’t have as large effect on that gas phase pollutant. So, Ken and I have have some things that we’re thinking about and working on, although NOx is not one of ‘em at the moment. Unless Ken’s gonna send me an email later today, telling me to start writing. But yes, there’s a lot of interesting things here.
Yeah, we're just kinda scratching the surface to thinking about how other pollutants behave in these changes. And Jordan Peccia spends a lot of time thinking about moisture, and how that's going to affect microbial activity at home. So we think about holes, and other standpoints. That's an area of interest. I encourage you to try to catch up with Jordan, because he'd love it. That is a real important factor on developmental health. Great. Thank you everybody.

And because we have across right of us, so we're happy, and thank you everyone for coming. Thank you again Ken and Drew. Thank you Ken.