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Original Study

# Nursing Home Design and COVID-19: Implications for Guidelines and Regulation



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## A B S T R A C T

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**Objectives:** Nursing homes (NHs) are important health care and residential environments for the growing number of frail older adults. The COVID-19 pandemic highlighted the vulnerability of NHs as they became COVID-19 hotspots. This study examines the associations of NH design with COVID-19 cases, deaths, and transmissibility and provides relevant design recommendations.

**Design:** A cross-sectional, nationwide study was conducted after combining multiple national data sets about NHs.

**Setting and Participants:** A total of 7785 NHs were included in the study, which represent 50.8% of all Medicare and/or Medicaid NH providers in the United States.

**Methods:** Zero-inflated negative binomial models were used to predict the total number of COVID-19 resident cases and deaths, separately. The basic reproduction number ( $R_0$ ) was calculated for each NH to reflect the transmissibility of COVID-19 among residents within the facility, and a linear regression model was estimated to predict  $\log(R_0 - 1)$ . Predictors of these models included community factors and NHs' resident characteristics, management and rating factors, and physical environmental features.

**Results:** Increased percentage of private rooms, larger living area per bed, and presence of a ventilator-dependent unit are significantly associated with reductions in COVID-19 cases, deaths, and transmissibility among residents. After setting the number of actual residents as the exposure variable and controlling for staff cases and other variables, increased number of certified beds in the NH is associated with reduced resident cases and deaths. It also correlates with reduced transmissibility among residents when other risk factors, including staff cases, are controlled.

**Conclusions and Implications:** Architectural design attributes have significant impacts on COVID-19 transmissions in NHs. Considering the vulnerability of NH residents in congregated living environments, NHs will continue to be high-risk settings for infection outbreaks. To improve safety and resilience of NHs against future health disasters, facility guidelines and regulations should consider the need to increase private rooms and living areas.

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Nursing homes (NHs) are important health care and residential environments for the growing number of frail older adults. In the United States, there are approximately 15,600 NHs with 1.7 million licensed beds, occupied by 1.4 million residents.<sup>1</sup> With the aging population, the need for high-quality long-term care will continue to increase, and the cost of NH care will remain a significant portion of national health expenditure. One of the important safety concerns in

NHs is the risk of infection outbreak, which tends to be high owing to their congregated living arrangements and vulnerable resident populations, who are more reliant on their proximal environments.<sup>2</sup>

Evidence-based approaches are critical in the design, planning, and management of health care facilities. A growing body of evidence has demonstrated the impact of hospital physical environments on outcomes such as infection control, fall prevention, and medical errors.<sup>3,4</sup> Such knowledge is critical for informing relevant regulations such as building codes and design guidelines. However, compared with hospitals, NHs are relatively understudied in terms of the impacts of their physical environment on resident safety and quality of care.<sup>5</sup>

The COVID-19 pandemic highlighted the vulnerability of NHs as they became hotspots of COVID-19 infections and deaths. As of March 2021, about 8% of those living in US NHs or other long-term care facilities have died of COVID-19, and the rate for NHs is even higher, at nearly 1 in 10.<sup>6</sup> These striking statistics are sobering reminders about the importance of providing safer environments in NHs.

A growing number of recent studies has explored the associations between NH characteristics and COVID-19–related outcomes. Three domains of variables have been frequently examined, including community factors, NH residents' characteristics, and NH management and performance. Among *community factors*, larger population size or density, urban location, and higher percentage of Black, deprived, or unemployed populations in the community have been related to a higher risk of COVID-19 infection and deaths in NHs.<sup>7–12</sup> In terms of the *NH residents' characteristics*, NHs with more older, male, non-White, and Medicaid and Medicare residents have been found to be more vulnerable to COVID-19,<sup>7,8,10,12–17</sup> whereas a few studies have reported nonsignificant roles.<sup>8,14</sup> Risk of mortality increased with the percentage of Black residents, age, and cognitive or functional impairment.<sup>15,17</sup> *NHs' management and performance factors* have also been frequently studied. Infection control policies have been shown to play significant roles in mitigating COVID-19 within NHs.<sup>18–20</sup> NHs with more prior health deficiencies or complaints were found to be more likely to have a COVID-19 case,<sup>9,16,21</sup> but 2 other studies reported prior infection violations to be insignificant.<sup>7,22</sup> Several studies reported that for-profit NHs have a higher risk compared with nonprofit or government owners,<sup>9,21,23</sup> although nonsignificant relationships have also been reported.<sup>7,24</sup> Furthermore, shortage of nursing staff and lower staff rating have been linked to a higher likelihood of a COVID-19 outbreak in most of the previous studies,<sup>10–12,14,21,23</sup> although a few studies showed insignificant relationships.<sup>9,22,25</sup>

Compared with these 3 domains of variables, *the physical environment of NHs* (eg, residential density, single- vs. multi-occupancy rooms) has been relatively understudied. But the small number of relevant studies are demonstrating promising results. For example, one study in Canada reported that shared bedrooms and bathrooms in NHs are positive correlates of larger and deadlier COVID-19 outbreaks.<sup>26</sup> A study about long-term care facilities in Atlanta, GA, found that more single bedrooms and more bedrooms with a bathroom and a sink helped control the spread of the virus.<sup>18</sup> Another study reported lower COVID-19 infection and mortality rates in Green House/small NHs than in larger traditional NHs.<sup>27</sup> A few other studies reported that smaller facility size/number of beds and lower density were associated with lower prevalence of COVID-19.<sup>7,9,10,12,16,19,21,26,28,29</sup> A few studies also suggested that poor indoor air quality and insufficient air ventilation in the NH might facilitate the spread of COVID-19 among NH residents.<sup>30–32</sup>

Overall, only a small number of studies have addressed the potential of using evidence-based design strategies to improve the safety of NHs during the pandemic, and most of them are limited to relatively small study areas and samples. This knowledge gap is rather striking considering the high risk of infection outbreaks in NHs and the strong

evidence linking design features of hospitals with hospital-acquired infections.<sup>3,4</sup> Infection control functions of such modifiable facility factors are the key to identifying effective intervention strategies to improve safety and care outcomes and guiding future practice. This study addressed this gap of knowledge by examining how specific design features of US NHs are associated with their total numbers of COVID-19 cases and deaths, as well as the transmissibility of the virus among residents.

## Methods

This is a nationwide, cross-sectional study using multiple nationwide data sets about NHs and COVID-19. It conceptualizes 4 domains of variables affecting COVID-19 cases, deaths, and transmissibility in NHs, including (1) community factors (eg, COVID-19 scenarios in the county where the NH is located, facility location, state), (2) NH residents' characteristics, (3) NH management and performance features, and (4) the NH's physical environmental attributes.

### Data Sources and Study Variables

One major data source for this study is the NH COVID-19 Public File, which includes weekly data reported by NHs to the Centers for Disease Control and Prevention. The data set includes information about resident cases and deaths, facility's designed capacity (ie, number of certified beds), actual number of residents, staff and personnel, supplies and PPE, and ventilator capacity and supplies. The first reporting was on May 17, 2020, but the data from the first few weeks may include cumulative data dating back to January 1, 2020. Therefore, this study chose to use the weekly data starting from week 3 (June 7, 2020). The week of December 20, 2020, was chosen as the end point for data inclusion because COVID-19 vaccines began to be administered in NHs around that time, and COVID-19 infections among residents started to drop significantly afterward (Figure 1).

Outcome variables include total COVID-19 resident cases, total COVID-19 resident deaths, and the basic reproduction number  $R_0$  calculated to reflect the extent of infection spread inside NHs.  $R_0$  is one of the most widely used metrics to quantify the contagiousness or transmissibility of infectious diseases.<sup>33</sup> It is usually interpreted as the expected number of new cases generated by each existing case in a total population. An outbreak is expected to continue when  $R_0 > 1$  and fade out when  $R_0 < 1$ . The magnitude of  $R_0$  depends on many factors, including the various aspects of the physical environment that we focus on in this article.<sup>34</sup> Various methods have been developed to estimate  $R_0$ , most of which are based on mathematical epidemiologic models.<sup>33</sup> Under the assumption that our study window is long enough to observe endemic equilibrium, and that the population is relatively enclosed in the sense that contact is mostly among the population within each NH with the implementation of no-visitation policies, we adopt a simple yet effective and robust estimation method, called the final size equation,<sup>35</sup> based on the percentage of susceptible persons in a population at endemic equilibrium. Specifically, we use

$$R_0 = -\log(1 - I/N) / (I/N),$$

where  $I$  is estimated by the maximum number of infected cases in each facility, and  $N$  is estimated by the maximum number of residents among the weeks when  $I$  achieved its maximum.

Independent variables are NHs' physical environment attributes. Information about the number of certified beds, being hospital based or not, and the presence of ventilator-dependent units was collected from the NH COVID-19 Public File. We also collected the square

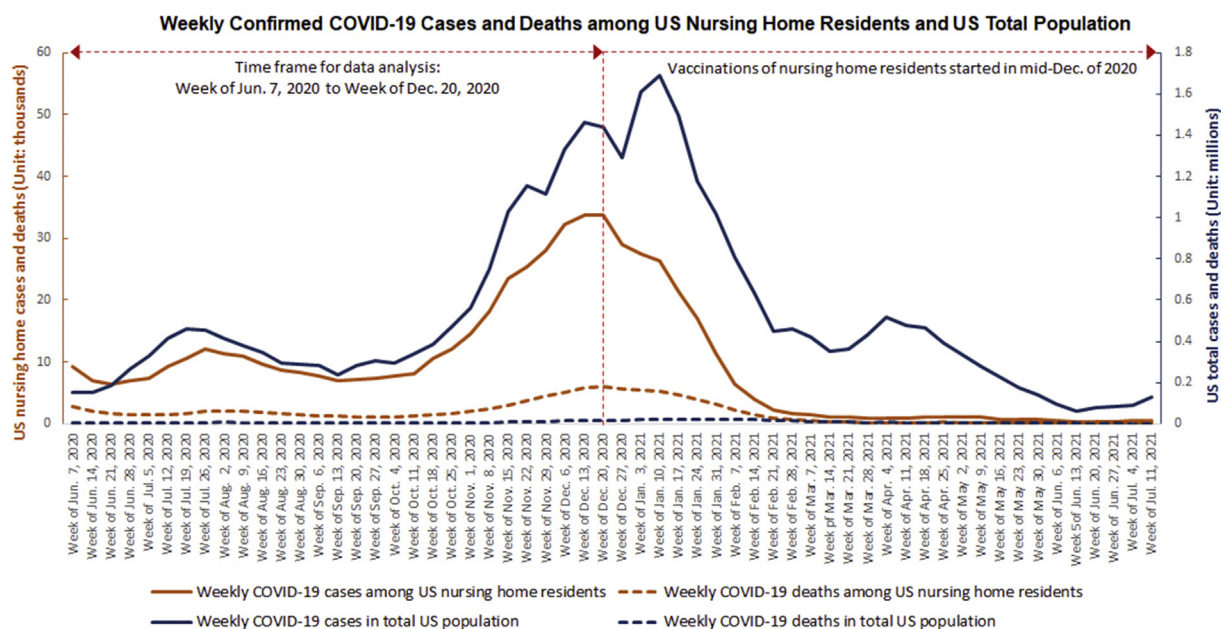


Fig. 1. Trends of COVID-19 confirmed cases and deaths in US nursing homes and in US total population.

footage data for NHs from each facility's most recent Medicare cost reports released in April 2021 and used that to calculate living area per certified bed as an indicator of residential density. The percentages of private rooms and double-occupancy rooms were calculated based on the room and board data in Skilled Nursing Facility (SNF)—Prospective Payment System (PPS) claims, which cover Medicare Part A beneficiaries and represent 12.3% of patient days in the study period. These are the best publicly available proxy measures we can identify for this national-level analysis. We also tried to identify data for indoor air quality and air ventilation patterns in NHs but were not able to locate such data. On the other hand, we included 1 partially related variable—NH's previous citations from infection control inspections—under the domain of facility management and rating, which was available from the NH COVID-19 Public File.

Confounding variables for this study include 3 domains, and the variable selection was informed by previous studies on this topic. The domain of contextual *community factors* includes (1) county-level sociodemographic factors from the 2019 American Community Survey 5-year summary data; (2) percentages of COVID-19 infections and deaths in the county, which was downloaded from the USA FACTS webpages ([usafacts.org](https://usafacts.org)); (3) types of facility location (eg, rural, small town, micropolitan, metropolitan) from Rural-Urban Commuting Area Codes provided by Economic Research Service of USDA; and (4) dummy variables for states to account for the possible impact from COVID-19—related state policies or other state-level effects.

The *NH resident characteristics* domain includes variables about residents' sociodemographic characteristics (eg, the average age, the percentage of female residents, and the percentage of White residents), as well as health condition, as captured by the average activities of daily living (ADL) scores (range: 0–28) and the percentages of residents with a Cognitive Function Scale (CFS) score of 1 (low cognitive impairment), 2 or 3 (moderate cognitive impairment), and 4 (severe cognitive impairment) from the 2019 Long-term Care Focus

Data.<sup>a</sup> ADL measures an individual's independence in 7 ADLs, with a higher score meaning lower independence, which generally implies worse health conditions. During the analysis, most of these variables (except the average ADL score) were excluded from the final models owing to multicollinearity with other variables or lack of significance or improvement in model fit. In addition, we initially considered some other variables for residents' characteristics, including the percentages of residents who were Hispanic, Black, less than 65 years old, and with certain health conditions (eg, bowel incontinence, bladder incontinence, congestive heart failure, urinary tract infection, obesity), but had to exclude them owing to large percentages of missing values.

Furthermore, the domain of *facility management and performance* includes (1) variables about type of ownership, quality ratings, staff nursing hours, and previous violations from the NH Compare data set; (2) confirmed staff COVID-19 cases; and (3) information about COVID-19 testing and preventive measures from the NH COVID-19 Public File.

#### Data Analysis

This study is a facility-level analysis using aggregated weekly data during our study period. Data were cleaned and analyzed using R, version 4.1.0 (R Foundation for Statistical Computing). Descriptive statistics of all study variables were reviewed first to help guide necessary data cleaning, outlier detection, variable transformation, and the selection of appropriate analytical methods. One of the outcome variables,  $R_0$ , was transformed to  $\log(R_0 - 1)$  to reach a normal distribution for the linear regression analysis. A few highly skewed predictors were recoded as binary variables (eg, number of citations and complaints) or using log transformation (eg, living area per certified bed).

Considering the large number of potential predictors, bivariate analysis was conducted first to examine the relationship between each predictor and each outcome variable. Only those with a significant bivariate relationship with at least 1 outcome were included in the multivariate model fitting process. The only exception was for the county-level sociodemographic factors and state variables, which were kept in the models because of their theoretical importance.

<sup>a</sup> Long-term Care Focus data is sponsored by the National Institute on Aging (1P01AG027296) through a cooperative agreement with the Brown University School of Public Health.

**Table 1**  
Descriptive Statistics for Outcome Variables and Nursing Home Physical Environmental Variables and Bivariate Relationships Between Physical Environmental Variables and the Outcomes

Variable	Descriptive Statistics				Bivariate Relationship (Coefficient) With the Outcome		
	Study Population		Study Sample		COVID-19 Cases	COVID-19 Deaths	Log( $R_0 - 1$ )
	n	Mean (SD)	n	Mean (SD)			
<b>Outcome variables</b>							
Total COVID-19 cases among residents	14,773	32.043 (31.380)	7785	36.762 (33.636)	—	—	—
Total COVID-19 deaths among residents	14,773	6.216 (8.827)	7345	6.772 (8.604)	—	—	—
$R_0$	12,297	1.490 (0.618)	6569	1.483 (0.604)	—	—	—
Transformed $R_0$ : $\log(R_0 - 1)$	12,297	-0.654 (0.606)	6569	-0.656 (0.604)	—	—	—
<b>Physical environmental variables</b>							
Living area per certified bed (unit: sq ft)	13,585	268.816 (1059.050)	7785	253.508 (954.344)	-0.021	-0.0001	-0.039**
Log(living area per certified bed)	13,491	5.282 (6.008)	7785	5.277 (0.568)	-0.117***	-0.030*	-0.106***
Percentage of private rooms (unit: 10%)	15,303	1.596 (2.960)	7785	1.641 (2.884)	-0.140***	-0.075***	-0.082***
Percentage of semiprivate rooms (unit: 10%)	15,303	8.029 (3.338)	7785	8.308 (2.939)	0.146***	0.078***	0.087***
Number of certified beds (unit: 10)	14,620	10.648 (5.879)	7785	11.911 (6.159)	0.459***	0.424***	0.001
Weeks with presence of a ventilator dependent unit (of 28 wk)	14,687	1.084 (5.439)	7785	1.222 (5.785)	-0.0003	-0.012	-0.042***

\* $01 \leq P < .05$ ; \*\* $.001 \leq P < .01$ ; \*\*\* $P < .001$ .

Three multivariate models were estimated to predict (1) total COVID-19 cases among residents within the NH ( $n = 7785$ ), (2) total COVID-19 deaths among residents ( $n = 7345$  after excluding facilities with mortality rate outliers), and (3) transmissibility of COVID-19, as captured by  $\log(R_0 - 1)$  ( $n = 6569$  after excluding facilities with no cases or incomplete data for calculation of  $R_0$ ). For model 1 and model 2, zero-inflated negative binomial models were used because the outcomes are count-based variables consisting of only nonnegative integer values, highly skewed and kurtotic with the variance greater than the mean, and with excessive zeros. The exposure variable in these 2 models was set to be the maximum number of residents during the study period. Model 3 is a linear regression model predicting  $\log(R_0 - 1)$ . With each model, 3 sets of predictors were tested: (1) community factors only, (2) further adding NHs' resident characteristics and management and performance factors, and (3) further adding physical environmental variables.

## Results

### Descriptive Statistics and Bivariate Test Results

A total of 7785 NHs were included in the study after excluding facilities missing key variables such as average ADL scores, living area, and quality measure ratings. This final NH sample represents 50.8% of all Medicare and/or Medicaid NH providers in the United States and is overall a representative sample in terms of the outcomes and the independent variables of physical environment factors (Table 1), or the confounding variables (Supplementary Table 1). The mean number of COVID-19 cases per NH in the study sample is 36.8, and the mean number of deaths is 6.8 per NH. These indicate extremely high infection and death rates, considering the mean number of beds in these NHs being only 119 and the average occupancy rate being 72.6% during the study period. All physical environmental variables showed significant bivariate relationships with the outcomes, with the

exception of the number of certified beds with  $\log(R_0 - 1)$  and the number of weeks with presence of a ventilator-dependent unit with 2 outcome variables (COVID-19 cases and deaths).

### Results From Multivariate Models

Overall, all 3 models achieved a good fit, with the adjusted  $R^2$  for model 3 being 0.338, and the pseudo- $R^2$  for model 1 and 2 being 0.491 and 0.511, respectively. When comparing the model fit from 3 sets of predictors within each model (Table 2), adding physical environmental variables led to significant improvement in model fit in all 3 models as indicated by corresponding reductions in AIC values. Furthermore, in Model 3, adding physical environmental variables explained 6.5% of the variance in  $\log(R_0 - 1)$ , where  $R_0$  reflects COVID-19 transmissibility among residents.

Table 3 presents the incidence rate ratios (IRRs) and the corresponding 95% confidence intervals (CIs) from model 1 (predicting resident cases) and model 2 (predicting resident deaths), as well as the beta ( $\beta$ ) coefficients and the corresponding 95% CIs from model 3 that predict COVID-19 transmissibility within NHs, as captured by  $\log(R_0 - 1)$ . IRRs can be interpreted as how the outcome variable will change relative to the base value of 1, with each 1-unit increase in the predictor.

For the domain of physical environmental factors, 4 variables demonstrated consistent results across 3 models. Each unit increase in  $\log(\text{living area/certified bed})$  is estimated to reduce the incidence rate of total resident cases by 11.6% (IRR = 0.884) and total deaths by 5.6% (IRR = 0.944). It is also negatively associated with the transmissibility of COVID-19, as captured by  $\log(R_0 - 1)$ , with a coefficient of  $-0.0651$ . Similarly, the percentage of private rooms for Medicare Part A beneficiaries shows favorable results, with each 10% increase estimated to reduce total resident cases by 2.0% (IRR = 0.980) and total resident deaths by 1.3% (IRR = 0.987), while being associated with decreased transmissibility (coefficient =  $-0.0103$ ). A 1-week increase in the

**Table 2**  
Model Fit Comparisons Across Different Sets of Predictors

Predictor Sets	Model 1: COVID-19 Cases		Model 2: COVID-19 Deaths		Model 3: Log( $R_0 - 1$ )	
	AIC	Pseudo- $R^2$	AIC	Pseudo- $R^2$	AIC	Adjusted $R^2$
Set 1: Community factors only	125,620	0.042	66954	0.122	21,937	0.056
Set 2: Set 1 + nursing homes' resident characteristics and management and performance factors	72,737	0.446	40,280	0.473	10,816	0.273
Set 3: Set 2 + nursing homes' physical environmental variables	66,830	0.491	37,415	0.511	9382	0.338

**Table 3**  
Multivariate Models Predicting COVID-19 Cases, Deaths, and Log( $R_0 - 1$ ) Among Nursing Home Residents

Variables	Model 1: COVID-19 Cases <sup>1</sup> (n = 7785)		Model 2: COVID-19 Deaths <sup>2</sup> (n = 7345)		Model 3: Log( $R_0 - 1$ ) (n = 6569)	
	IRR	95% CI	IRR	95% CI	Beta	95% CI
Log(theta)	1.874***	(1.8050, 1.9430)	2.002***	(1.8921, 2.1118)	—	—
Intercept	0.641*	(0.4050, 0.8764)	0.051***	(0.0278, 0.0738)	-0.4995***	(-0.753, -0.2464)
Community factors (county) <sup>3</sup>						
Population aged ≥65 y (unit: %)	0.995	(0.9883, 1.0019)	0.995	(0.9869, 1.0041)	-0.0022	(-0.0068, 0.0024)
Hispanic population (unit: %)	0.993***	(0.9911, 0.9958)	0.998	(0.9950, 1.0008)	-0.0047***	(-0.0063, -0.0030)
Non-Hispanic African American population (unit: %)	0.999	(0.9968, 1.0011)	0.999	(0.9965, 1.0018)	-0.0011	(-0.0025, 0.0004)
Non-Hispanic Asian population (unit: %)	0.992**	(0.9866, 0.9981)	0.974***	(0.9670, 0.9814)	-0.0044*	(-0.0083, -0.0006)
Median annual household income (unit: \$1000)	1.001	(0.9995, 1.0029)	1.005***	(1.0027, 1.0069)	0.0007	(-0.0005, 0.0018)
COVID-19 cases in county (unit: %)	1.013	(0.9954, 1.0304)	0.966**	(0.9451, 0.9867)	0.0170**	(0.0049, 0.0291)
COVID-19 deaths in county (unit: per 1000 residents)	1.170***	(1.1149, 1.2254)	1.348***	(1.2693, 1.4277)	0.1014***	(0.0687, 0.1341)
Small town (reference: rural area)	1.043	(0.9173, 1.1691)	0.939	(0.7918, 1.0871)	0.0398	(-0.0445, 0.1241)
Micropolitan (reference: rural area)	1.038	(0.9198, 1.1560)	0.943	(0.8042, 1.0826)	0.0494	(-0.0302, 0.1289)
Metropolitan (reference: rural area)	1.031	(0.9166, 1.1459)	0.914	(0.7811, 1.0475)	0.0394	(-0.0377, 0.1164)
Resident characteristics <sup>4</sup>						
Average ADL scores (0-28)	0.997	(0.9874, 1.0073)	1.022***	(1.0090, 1.0348)	0.0048	(-0.0017, 0.0114)
Facility management and rating						
Number of residents admitted or readmitted who were previously hospitalized and treated for COVID-19/weekly average of residents (unit: %)	1.002***	(1.0015, 1.0027)	1.006***	(1.0052, 1.0069)	0.0005**	(0.0001, 0.0008)
COVID-19 confirmed staff	1.026***	(1.0244, 1.0267)	1.016***	(1.0150, 1.0175)	0.0163***	(0.0156, 0.0170)
Owner type—government (reference: for profit)	0.900*	(0.8113, 0.9879)	0.917	(0.8054, 1.0285)	-0.0732*	(-0.1390, -0.0073)
Owner type—nonprofit (reference: for profit)	0.864***	(0.8210, 0.9063)	0.938*	(0.8799, 0.9955)	-0.0840***	(-0.1177, -0.0502)
Citations from infection control inspections (yes/no)	1.100***	(1.0573, 1.1424)	1.063*	(1.0122, 1.1138)	0.0753***	(0.0487, 0.1019)
Substantiated complaints (yes/no)	1.041	(0.9947, 1.0877)	0.982	(0.9272, 1.0360)	0.0226	(-0.0077, 0.0530)
Health inspection rating	0.975**	(0.9593, 0.9916)	0.977*	(0.9564, 0.9967)	-0.0217***	(-0.0331, -0.0103)
Quality measures rating	0.983*	(0.9658, 0.9997)	0.988	(0.9674, 1.0094)	-0.0206***	(-0.0325, -0.0088)
Staff rating	0.958***	(0.9380, 0.9771)	1.014	(0.9885, 1.0394)	-0.0232**	(-0.0373, -0.0092)
Weeks receiving residents' test result in less than a day	0.998	(0.9914, 1.0048)	1.004	(0.9960, 1.0122)	-0.0020	(-0.0066, 0.0026)
Weeks testing residents with new signs or symptoms	1.008*	(1.0004, 1.0148)	1.015***	(1.0065, 1.0236)	0.0054*	(0.0006, 0.0102)
Weeks testing asymptomatic residents in a unit or section after a new case	1.006	(0.9954, 1.0161)	1.000	(0.9878, 1.0113)	0.0043	(-0.0026, 0.0113)
Weeks testing asymptomatic residents facility wide after a new case	0.996	(0.9895, 1.0024)	0.992*	(0.9840, 0.9993)	0.0011	(-0.0033, 0.0054)
Weeks testing asymptomatic residents without known exposure as surveillance	0.999	(0.9948, 1.0033)	0.990***	(0.9849, 0.9953)	0.0002	(-0.0027, 0.0031)
Weeks testing residents in another subgroup	0.994	(0.9866, 1.0023)	0.999	(0.9888, 1.0090)	-0.0040	(-0.0094, 0.0014)
Weeks with point-of-care tests performed on residents	1.006*	(1.0009, 1.0104)	1.001	(0.9957, 1.0070)	0.0052**	(0.0020, 0.0084)
Facility physical environment						
Log(living area per certified bed)	0.884***	(0.8517, 0.9169)	0.944*	(0.9007, 0.9873)	-0.0651***	(-0.0912, -0.0390)
Private rooms for Medicare part A beneficiaries (unit: 10%)	0.980***	(0.9734, 0.9871)	0.987**	(0.9786, 0.9963)	-0.0103***	(-0.0149, -0.0057)
Weeks with ventilator-dependent unit of 28 wk	0.991***	(0.9877, 0.9939)	0.988***	(0.9843, 0.9920)	-0.0059***	(-0.0080, -0.0038)
Number of certified beds (unit: 10 beds)	0.953***	(0.9496, 0.9567)	0.965***	(0.9603, 0.9689)	-0.0310***	(-0.0337, -0.0283)

IRR, incidence rate ratio.

\*.01 ≤  $P < .05$ ; \*\*.001 ≤  $P < .01$ ; \*\*\* $P < .001$ .

<sup>1</sup>For model 1, total COVID-19 confirmed cases in county and total number of residents admitted or readmitted who were previously hospitalized and treated for COVID-19 were used to model the logit part in modeling excess zero counts.

<sup>2</sup>For model 2, total COVID-19 confirmed cases among residents and staff was used to model the logit part in modeling excess zero counts.

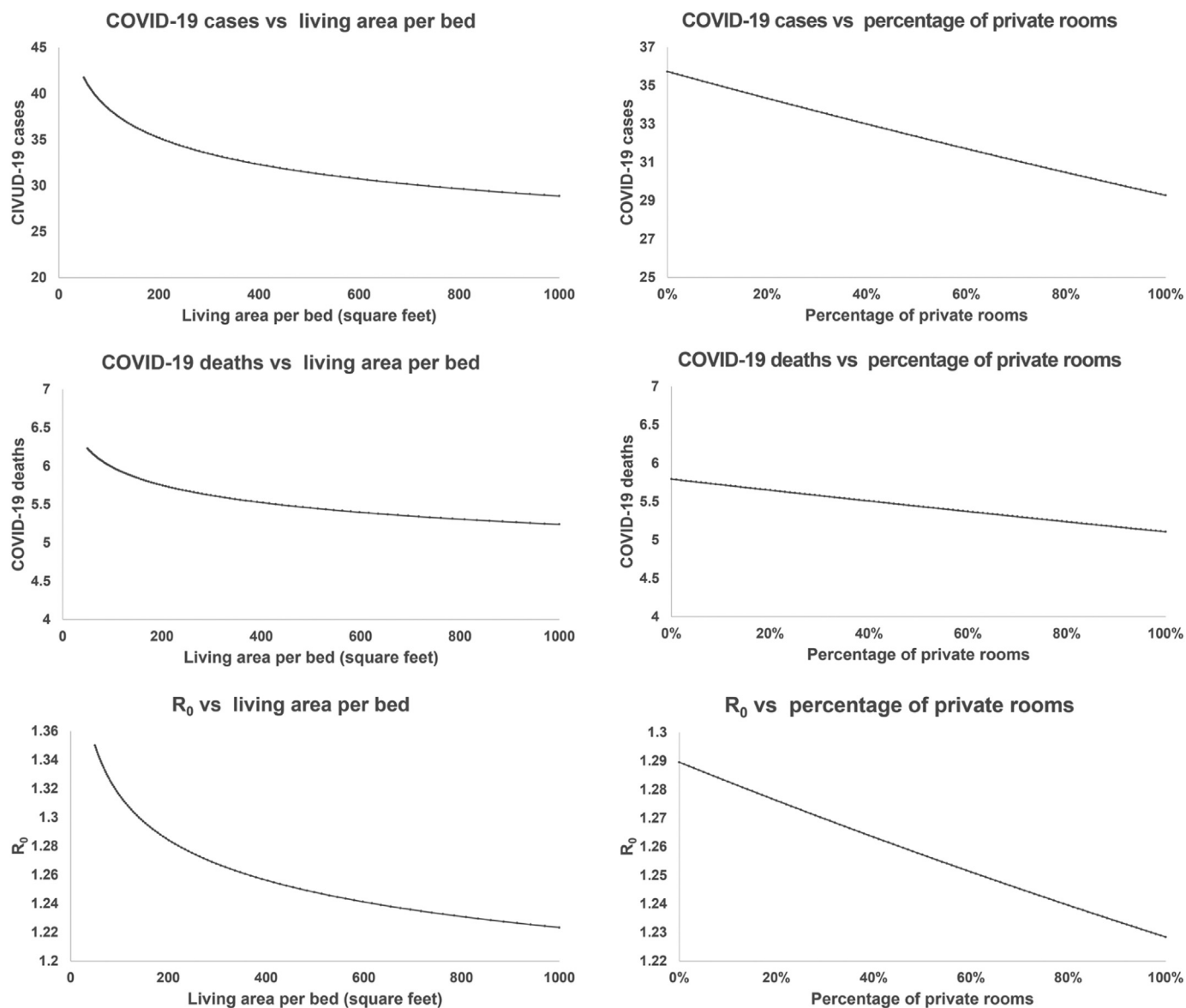
<sup>3</sup>Dummy variables for states were also tested and the IRRs (or beta coefficients) and 95% CIs for those significant ones are summarized below:

IRRs (95% CIs) for significant state variables in model 1: Connecticut: 1.228\* (0.9903, 1.4654); Florida: 0.767\*\*\* (0.6491, 0.8841); Hawaii: 0.435\*\* (0.1956, 0.6754); Maine: 0.484\*\* (0.2702, 0.6968); Michigan: 0.798\*\* (0.6626, 0.9338); Missouri: 1.225\* (1.0166, 1.4335); North Dakota: 0.591\*\*\* (0.4153, 0.7675); New York: 0.698\*\*\* (0.5848, 0.8119); Oregon: 0.775\* (0.5832, 0.9673); Texas: 1.350\*\* (1.1059, 1.5949); Wisconsin: 0.828\* (0.6754, 0.9806).

IRRs (95% CIs) for significant state variables in model 2: Arkansas: 1.542\* (0.9687, 2.1148); California: 1.270\* (0.9882, 1.5516); Colorado: 1.416\*\* (1.0701, 1.7613); Connecticut: 1.620\*\*\* (1.2486, 1.9919); Florida: 0.755\*\* (0.6157, 0.8947); Hawaii: 2.615\* (0.4344, 4.7951); Illinois: 1.591\*\*\* (1.2964, 1.8863); Indiana: 1.517\*\*\* (1.2081, 1.8263); Louisiana: 1.477\* (0.9248, 2.0297); Massachusetts: 1.440\*\*\* (1.1385, 1.7409); Maryland: 1.260\* (0.9871, 1.5322); Minnesota: 1.415\*\* (1.1203, 1.7095); Missouri: 1.474\*\*\* (1.1783, 1.7704); North Carolina: 1.321\*\* (1.0701, 1.5720); New Jersey: 1.643\*\*\* (1.2856, 1.9999); Ohio: 1.349\*\*\* (1.1091, 1.5887); Pennsylvania: 1.484\*\*\* (1.2152, 1.7534); Rhode Island: 1.747\*\*\* (1.2519, 2.2420); South Dakota: 1.801\*\* (1.0920, 2.5094); Vermont: 2.044\* (0.7221, 3.3664); Washington: 1.693\*\*\* (1.2307, 2.1543); Wisconsin: 1.342\* (1.0385, 1.6457).

Betas (95% CIs) for significant state variables in model 3: California: 0.147\* (0.0191, 0.2752); Florida: -0.139\* (-0.2456, -0.0328); Maine: -0.304\* (-0.6024, -0.0053); Michigan: -0.165\*\* (-0.2816, -0.0485); Minnesota: -0.122\* (-0.2388, -0.0052); Missouri: 0.167\*\* (0.0474, 0.2875); North Dakota: -0.532\*\*\* (-0.7436, -0.3198); New York: -0.196\*\*\* (-0.3102, -0.0818); Texas: 0.226\*\*\* (0.0985, 0.3532).

<sup>4</sup>For resident characteristics, several other variables were included in the analyses but excluded from the final models because of multicollinearity with other variables or lack of significance or improvement in model fit. These include the average age, the percentage of female residents, the percentage of White residents, and the percentages of residents with a Cognitive Function Scale (CFS) score of 1 (low cognitive impairment), 2 or 3 (moderate cognitive impairment), and 4 (severe cognitive impairment). In addition, we initially considered some other variables for residents' characteristics, including the percentages of residents who were Hispanic, Black, <65 years old, and with certain health conditions (eg, bowel incontinence, bladder incontinence, congestive heart failure, urinary tract infection, and obesity), but had to exclude them owing to large percentages of missing values.



**Fig. 2.** Predicted changes in COVID-19 outcomes with changes in design factors. Condition for the simulated scenarios: state = California; urban-rural category = metropolitan; ownership type = for profit. Median values were used for all other covariates.

number of weeks with a ventilator-dependent unit during the 28-week study period is projected to reduce the incidence rate of resident cases by 0.9% and resident deaths by 1.2%. It is also negatively associated with  $\log(R_0 - 1)$  (coefficient =  $-0.0059$ ). After setting the number of residents as the exposure variable and controlling staff cases, every 10 additional certified beds is estimated to reduce the incidence rate of resident cases (by 4.7%) and resident deaths (by 3.5%); it is also negatively associated with COVID-19 transmissibility (coefficient =  $-0.0310$ ) when other risk factors, including staff cases, are controlled. Figure 2 illustrates simulated scenarios that visualize how COVID-19 cases, deaths, and transmissibility among residents are expected to change with changes in the living area per certified bed and the percentage of private rooms in a given condition.

Among *community factors*, the rate of COVID-19 deaths in the county where the NH is located is associated with increased NH resident cases, deaths, and transmissibility. Total rate of COVID-19 cases in the county is positively associated with COVID-19 transmissibility in NHs, negatively associated with COVID-19 deaths, and not associated with NH resident cases. Among the county-level

sociodemographic factors, after controlling county-level COVID-19 infection and death rates and other factors, a higher percentage of non-Hispanic Asians in the country is associated with reduced NH resident cases, deaths, and transmissibility; a higher percentage of the Hispanic population is associated with lower levels of NH resident cases and COVID-19 transmissibility in NHs but not significant for NH resident deaths.

For *NH resident characteristics*, higher ADL scores (indicating greater dependency in everyday activities) were associated with an increase in NH resident deaths after controlling for other factors. Some of the *NH facility management and rating factors* also showed significant results. The variable of number of residents admitted or readmitted who were previously hospitalized and treated for COVID-19/weekly average of residents was associated with increased resident cases, resident deaths, and COVID-19 transmissibility. Similar results were reported for the variables of NH staff COVID-19 cases, citations from previous infection control inspections, and for-profit ownership. For most of the quality rating variables, higher ratings were associated with better COVID-19 related outcomes.

## Discussions

This study adds to the limited knowledge about the influence of physical environmental factors on COVID-19–related outcomes in NHs. We found evidence supporting their significant roles after controlling other NH or community (county-level) factors. This is especially timely given the COVID-19 context and limited previous studies on this topic. Two innovations of this research comes from (1) the estimation of COVID-19 transmissibility among NH residents, which is typically only calculated for community-based studies and (2) the explicit analysis of how physical environmental features have contributed to the COVID-19 outbreak in US NHs.

Results about confounding factors are mostly consistent with previous findings. For physical environmental factors, *reduced density* and *increased percentage of private rooms* are related to reduced COVID-19 resident cases and resident deaths, which is consistent with the limited number of previous studies. In addition, these 2 factors are also associated with reduced COVID-19 transmissibility among NH residents, further supporting their important role in infection mitigation. After setting the number of residents as the exposure variable and controlling staff cases, NH capacity (ie, number of certified beds) was associated with reduced COVID-19 resident cases and resident deaths; it was also associated with reduced transmissibility of COVID-19 among NH residents when other risk factors, including staff cases, are controlled. This may appear to be conflicting with previous studies linking increased number of beds to worse COVID-19 outcomes. However, it is likely due to the fact that other studies used the number of beds to capture the extent of exposure to other residents, whereas our models included the number of actual residents as the exposure variable and used the number of certified beds as a predictor that reflects NH's designed capacity—an important design factor. Considering the ongoing discussion about the future of policy to mitigate current and future epidemics in NHs, our study findings are pointing to *greater area per bed and higher percentage of private rooms* as favorable design strategies. These findings also suggest that it may not be necessary to scale down the NH's designed capacity for better infection control as long as spacious living areas and more single-occupancy rooms are provided, and residents' contact with infected staff can be limited.

A few limitations need to be addressed. First, weekly data for COVID-19 cases and deaths in NHs are not available for the earliest stage (up to mid-May 2020) of the pandemic, and this limited the temporal coverage of our data analysis. Second, information about NHs' specific design features are limited. The data about NH's square footage was collected from each NH's most recent Medicare cost reports. This is the best available data but there is limited information about quality of these data. However, it (log-transformed square feet per certified bed) showed significant associations with all 3 outcome variables. The percentage of private rooms used in this study was calculated based on SNF—PPS room and board data, which only cover Medicare Part A beneficiaries (accounting for 12.3% of total patient/resident days in NHs). This is the best publicly available data we could identify for this national-level analysis. Further more, it is reasonable to expect that other design attributes such as the layout of resident rooms, air quality or air ventilation systems of NHs would also have important roles in infection control during the pandemic, but such data are not available on a national scale. Third, there is limited nationwide data about NH residents' commodity and facility policies regarding infection mitigation measures. Some of the resident data from the Long-term Care Focus data had significant portions of missing values. Meanwhile, other COVID-19 risk factors highlighted by the Centers for Disease Control and Prevention such as cancer, chronic kidney disease, chronic liver disease, dementia, and diabetes are not included in the Long-term Care Focus data. Finally, the data from Long-term Care Focus are somewhat outdated (from 2019), but it is

the best nationwide publicly available data. These limitations highlight the importance of systematic data collection about detailed environmental attributes of NHs, resident attributes, and NH policies in the future to allow better monitoring to ensure safer care while also enabling more in-depth research for effective infection control in NHs.

## Conclusions and Implications

This study contributes to the much-needed knowledge about the associations between NHs' specific design attributes and COVID-19 cases, deaths, and transmissibility among residents. The positive impacts of greater living area per bed and higher percentage of private rooms in reducing COVID-19 cases, deaths, and transmissibility provide a nascent empirical database to help inform the design, planning, and management of NHs. Future facility guidelines should consider these results in their recommendations for living areas and room types. Future practice and Medicare and Medicaid policies can also benefit from a more systematic effort in collecting detailed information about NH design (eg, room types and sizes, building floor plans, site plans, indoor air quality, and air ventilations patterns) and residents' characteristics. Such efforts will also enable more in-depth research to further understand and optimize roles of design features in relation to infection control or other quality of life measures among NH residents. More research is needed for the roles of air ventilation patterns and the cost effectiveness of the proposed design changes in NHs, while taking infection control and resident safety into consideration of the financial outcomes.

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## Supplementary Data

Supplementary data related to this article can be found online at <https://doi.org/10.1016/j.jamda.2021.12.026>.

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**Supplementary Table 1**

Descriptive Statistics for Confounding Variables and Their Bivariate Relationships With the Outcome Variables

Variable	Descriptive Statistics				Bivariate Relationship (Coefficient) With the Outcome		
	Study Population		Study Sample		COVID-19 Cases	COVID-19 Deaths	Log( $R_0 - 1$ )
	n	Mean (SD) or % of Yes	n	Mean (SD) or % of Yes			
<b>Community factors (county)</b>							
Population aged $\geq 65$ y (unit: %)	15,367	16.785 (4.072)	7785	16.834 (4.095)	-0.060***	-0.056***	-0.028*
Hispanic population (unit: %)	15,367	13.707 (15.316)	7785	14.080 (14.871)	0.030**	0.038***	-0.008
Non-Hispanic African American population (unit: %)	15,367	11.039 (12.690)	7785	11.265 (12.178)	0.068***	0.060***	-0.002
Non-Hispanic Asian population (unit: %)	15,367	3.877 (5.394)	7785	4.431 (5.647)	-0.007	0.020	-0.072***
Median annual household income (unit: \$1000)	15,367	61.362 (16.618)	7785	63.601 (17.324)	-0.024*	0.056***	-0.084***
COVID-19 cases in county (unit: %)	15,367	5.637 (2.169)	7785	5.333 (1.915)	0.082***	0.060***	0.160***
COVID-19 deaths in county (unit: per 1000 residents)	15,367	1.018 (0.654)	7785	1.012 (0.629)	0.131***	0.267***	0.043***
Small town (reference: rural area)	15,373	10.43%	7785	7.04%	-0.046***	-0.059***	0.024
Metropolitan (reference: rural area)	15,373	13.80%	7785	12.36%	-0.007	-0.034**	0.052***
Metropolitan (reference: rural area)	15,373	68.80%	7785	76.94%	0.069***	0.090***	-0.050***
<b>Resident characteristics</b>							
Average ADL scores (0-28)	9598	16.820 (2.540)	7785	16.905 (2.209)	-0.004	0.035**	-0.022
<b>Facility management and rating</b>							
Number of residents admitted or readmitted who were previously hospitalized and treated for COVID-19/weekly average of residents (unit: %)	14,773	13.910 (44.086)	7785	14.418 (37.047)	0.116***	0.235***	0.071***
COVID-19 confirmed staff	14,773	27.344 (21.131)	7785	30.738 (22.645)	0.704***	0.546***	0.425***
Owner type—government (reference: for profit)	15,317	6.32%	7785	3.99%	0.009	0.014	-0.009
Owner type—nonprofit (reference: for profit)	15,317	23.42%	7785	22.27%	-0.114***	-0.0344**	-0.085***
Citations from infection control inspections (yes/no)	15,317	38.96%	7785	40.40%	0.108***	0.095***	0.106***
Substantiated complaints (yes/no)	15,317	61.70%	7785	65.72%	0.123***	0.068***	0.072***
Health inspection rating	15,101	2.807 (1.275)	7785	2.744 (1.253)	-0.122***	-0.079***	-0.074***
Quality measures rating	15,084	3.762 (1.216)	7785	3.883 (1.147)	-0.057***	-0.028*	-0.085***
Staff rating	13,857	3.267 (1.178)	7785	3.271 (1.137)	-0.176***	-0.097***	-0.066***
Weeks receiving residents' test results in less than a day	14,812	1.979 (3.266)	7785	1.581 (2.932)	0.010	0.009	0.011
Weeks testing residents with new signs or symptoms	14,823	1.849 (2.781)	7785	1.990 (2.951)	0.178***	0.105***	0.117***
Weeks testing asymptomatic residents in a unit or section after a new case	14,823	1.052 (1.941)	7785	1.137 (2.030)	0.204***	0.126***	0.122***
Weeks testing asymptomatic residents facility-wide after a new case	14,823	3.207 (3.120)	7785	3.330 (3.171)	0.174***	0.083***	0.013***
Weeks testing asymptomatic residents without known exposure as surveillance	14,817	6.157 (4.786)	7785	6.720 (4.874)	0.142***	0.117***	0.037**
Weeks testing residents in another subgroup	14,817	0.990 (2.257)	7785	1.076 (2.369)	-0.016	0.024*	-0.033**
Weeks with COVID-19 point-of-care tests performed on residents	14,610	5.284 (4.434)	7785	5.260 (4.505)	0.133***	0.087***	0.109***

\*.01  $\leq P < .05$ .\*\*.001  $\leq P < .01$ .\*\*\* $P < .001$ .